University of Southern Queensland
Faculty of Health, Engineering and Sciences

Study on Sisal Fibres as Insulator in Building Materials

Dissertation submitted by

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Abstract

In this current era, there are some concerns of using synthetic fibres in regards to their impact on the environment since they are non-recyclable and non-degradable. There are many attempts by various groups of engineers and researchers to use natural fibres in engineering applications, in the hopes of replacing synthetic fibres with natural fibres. In this project, the possibility of using natural fibres in building materials is investigated in terms of their compression strength and heat conductivity. Sisal fibres are selected as reinforcement for gypsum walls for the application in industrial and commercial buildings. To gain high interfacial adhesion of the sisal fibres with gypsum, a study on the optimum chemical treatment concentration of NaOH (0-10 %) is considered. To study the heat conductivity of the composites, a newly designed heat conductivity test setup is developed to study the influence of different volume fractions of glass and sisal fibres on the conductivity of gypsum. In addition, compressive test was performed for the selected materials. Failure mechanisms of the samples after compressive testing are examined with the aid of the scanning electron microscopy (SEM).

The results revealed that the alkalization on the sisal fibres have provided different levels of interfacial adhesion in the composites which were pronounced on the surface topography of the fibres. Based on this observation and supported by other literatures, 6% NaOH was selected as the optimal concentration for composite fabrication. From the compressive test, it was observed that the addition of fibres to the gypsum matrix improves the compressive strength and resulted in reduced brittleness. For sisal fibre-gypsum composite, the optimum fibre content is at 25 vol.% while for glass fibre-gypsum composite, the optimum fibre content is at 30 vol.%. The thermal conductivity resulted showed that pure gypsum was found to have the highest thermal conductivity. The thermal conductivity of the composites decrease with the increment of fibre volume fraction for both synthetic and natural addition of the fibres. Sisal fibre-gypsum composites performs slightly better at

insulating heat as compared to glass fibre-gypsum composites possibly due to its porous nature, as heat transfer is impeded by the presence of air voids.

Keywords: wall; sisal fibre, natural fibre; building materials, civil; construction; thermal conductivity.

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Table of Contents

List of Figures

List of Tables

Chapter 1 Introduction

1.1 Introduction

In recent years, there is an increase in interest in the development of natural fibres for industrial applications by engineers and researchers. Many efforts are focused on the possibility of replacing natural fibres with the more conventional synthetic fibres, such as glass, carbon and aramid. Natural fibres possess good properties, suitable to be used as engineering materials. These properties include high strength, low weight, corrosion resistance, low cost, less health hazards, and obtained from renewable resources (Chen, Li & Ren 2011; Ho et al. 2012). A particular interest for the use of natural fibres is in the form of reinforcing fibres in composite materials. This can be observed in the automotive industry, whereby in the last decades, many Western European automotive manufactures, such as Audi, BMW and Volkswagen are using these types of composites within various parts of a vehicle, mainly as interior linings, padding and panelling (Suddell 2008).

Glass fibres are one of the most widely used interior construction material in the world. They are widely used to reinforce plastics as they are relatively cheaper than aramid and carbon but with fairly good mechanical properties (Wambua, Ivens & Verpoest 2003). The production of glass fibres create lots of environmental issues associated with the significant increase of waste disposal sites. In addition, the lack of landfills in some areas and how to regulate them is one of the major challenges that current civil engineers are facing. In Australia, 8.5 million tonnes of construction and demolition waste was disposed to landfill in the year 2008-2009 (Hyder Consulting 2011). Thus, it is urgent to promote sustainable building materials to reduce the negative impact on the environment brought by non-biodegradable materials.

The civil engineering industry had witnessed many changes and development in the use of building materials. Most recently is the application of fibres as reinforcement for cement, concrete and polymers. Another possible combination is with gypsum, to provide finishing interior work, panelling and partition walls in buildings. It is estimated that about 95% of total gypsum produced is consumed by the building sector (Eires, Camões & Jalali 2008). The main contribution of this material is to provide comfort to people residing in buildings due to its thermal and acoustical properties.

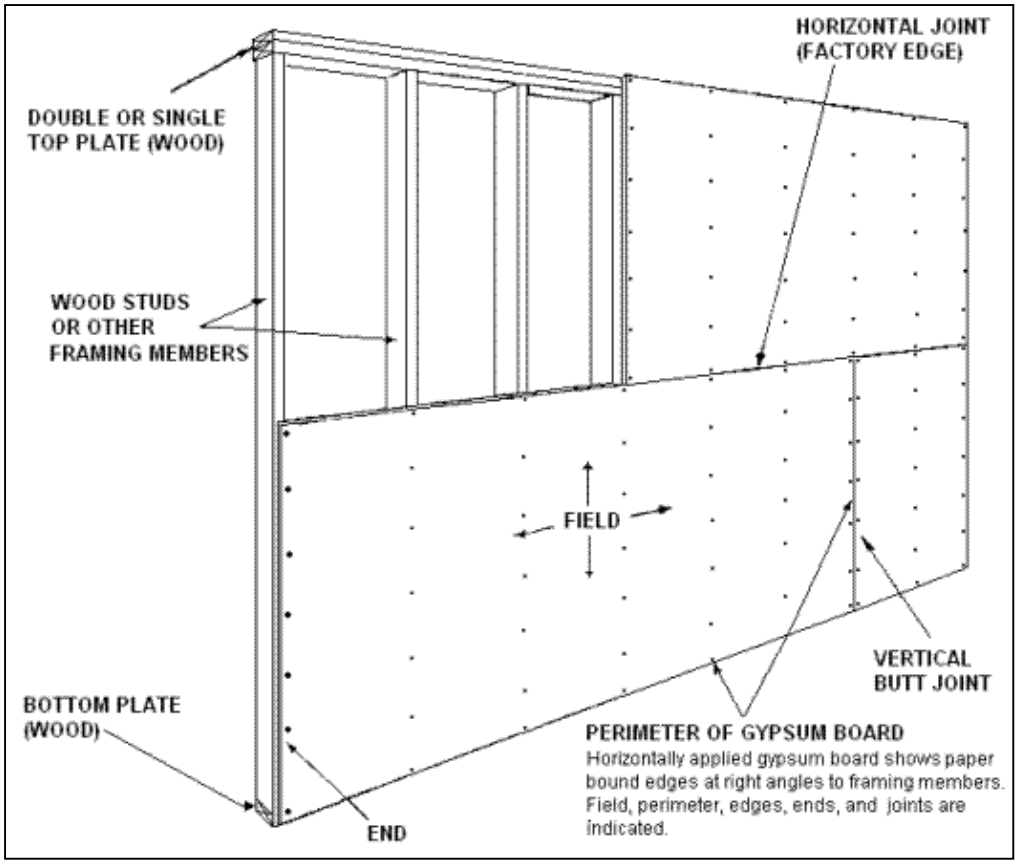


Figure 1.1: Horizontally applied gypsum wallboard (Gypsum-Association 2012)

Gypsum board is also known as drywall, wallboard and plasterboard. It has a non-combustible core and paper facers, therefore, making it advantageous from other panel–type building products, such as plywood, hardboard, and fibreboard. One of the applications of gypsum board is shown in Figure 1.1. In practice, gypsum boards

are sometimes faced with various materials, including paper and fibre glass mats (Gypsum-Association 2012). Therefore, in this study, the performance of gypsum in combination with natural fibre is evaluated. Its thermal insulation property is primarily observed for any improvement or deterioration with the addition of sisal fibres.

1.2 Study Motivation

Developing sustainable and environmental-friendly buildings is a common motivation for engineers and researchers towards a green, clean, and resilient world for all. The problem arising from excess waste disposal from non-biodegradable materials have recently raised concerns from governments, researchers and industrial sectors on the usage and disposal of these types of synthetic materials. One of the approaches ventured is the use of renewable materials that are biodegradable when they are no longer required.

Such materials are commonly plant based. This is due to their renewability and abundance. However, it cannot be ignored that natural fibres derived from plants are susceptible to moisture, thermal, and microorganism degradation (Azwa et al. 2013). Therefore, immense efforts are required to sufficiently study the performance of natural fibres as building materials before they can fully replace synthetic fibres.

This study is motivated by the need to expand the knowledge on the use of natural fibres in the construction industry. Specifically, this study will focus on the effect of heat conductivity of gypsum panels reinforced with natural fibres. The developed material may contribute to the improvement of thermal insulation properties of building panels.

1.3 Aims and Objectives

It is common practice to incorporate glass fibres as reinforcements in gypsum. The purpose of this project is to compare the performance of gypsum reinforced with both glass fibres and natural fibres, namely sisal fibres. This assessment will involve investigating current literatures on the topic and also conduct testings on the gypsum composites to determine and compare their properties.

In order to achieve these aims, the following objectives had to be accomplished:

1. Research background information on previous studies and experimental works conducted on natural fibre composites.
2. Conduct alkali treatment on sisal fibres in order to provide better interlocking with the gypsum matrix. Different concentration of sodium hydroxide (NaOH) (2, 4, 6, 8, and 10 wt%) is introduced to the fibres to observe the optimum treatment concentration.
3. Perform observation on the treated and untreated sisal fibres using scanning electron microscopy (SEM). This is to study the effect of alkali treatment on the surface of the fibres.
4. Fabricate gypsum-fibre composites with different fibre contents for both glass and sisal fibres. This will give a better understanding on the effects of fibres on the properties of the composites.
5. Study the compressive behaviour of the developed materials in order to evaluate and compare their mechanical property.
6. Develop a setup to test the heat resistance of the composite samples.
7. Investigate the heat conductivity of the composite materials in order to evaluate and compare their thermal insulation property.

1.4 Dissertation Overview

This dissertation is divided into seven chapters which has the following structure:

Chapter 1: Provides an introduction and background information on natural fibres as engineering material, the motivation of this research project, and the objectives that will be covered in this study.

Chapter 2: Provides reviews on recent literatures related to the topic of this research.

Chapter 3: Describes the methodology used to achieve the objectives of this study, covering materials selection, fibre alkali treatment and the composite fabrication

processes, the visual observation of fibre surface using scanning electron microscopy, as well as the experimental programme of the thermal and mechanical testing procedures.

Chapter 4: Presents all the results obtained from experimental program, which includes the physical and morphological observations of treated and untreated sisal fibres, the outcome of the compression test performed on the composites, indicating the mechanical strength of the samples, and the result of the heat conductivity test, analysing the thermal insulating properties of the samples.

Chapter 5: Concludes the findings of this study and addresses whether the objectives were met. Provides recommendations on future development of natural fibres as insulators in building materials.

Chapter 2 Literature Review

2.1 Introduction

This chapter presents the literature review conducted on different research areas related to sisal fibres and its composites. This includes the applications of natural fibres as building materials, the properties of sisal fibres, and experimental studies on sisal fibre composites related to its thermal and mechanical properties. The information obtained in this chapter was used to assist in the outlining and planning of this research program.

2.2 Materials in building construction

The construction industry is in constant development whereby traditional materials used as building blocks are continuously replaced as better materials are developed. Traditional materials such as timber, stones, rocks, bricks, straws, mud etc. have made way for more robust materials such as concrete and steel. Most recent is the development of fibre reinforced composites, with matrices including polymer, ferrocement, and gypsum.

2.2.1 Advantages and disadvantages of fibre reinforced composites

Composite materials have existed even approximately 3500 years ago where brittle building materials such as sun baked bricks were reinforced with horse-hair, straw and other vegetable fibres. In modern times, in about 1900, the concept of fibre reinforcement was developed on brittle cement-based paste reinforced with asbestos fibres. The Hatschek technology was invented for production of plates for roofing, pipes, etc. More recently, glass fibres were proposed for reinforcement of cement paste and mortar by Biryukovichs (Brandt 2008). Since 1960 onwards, advanced composite materials have found to have expanded especially in areas such as

aerospace, marine and automobile industries. This is due to their good engineering properties such as high specific strength and stiffness, lower density, high fatigue endurance, high damping and low thermal coefficient (in fibre direction) (Pendhari, Kant & Desai 2008). In addition, the structural capacity of FRP can be tailored and maximized by aligning fibres along its optimal orientation (Li et al. 2006). This shows that FRP is a flexible material and can be applied on many types and shapes of surfaces. Furthermore, FRP composites are light weight and highly durable in many environments. The light weight is an attractive characteristic as it makes construction and rehabilitation works much easier as heavy handling equipment is not needed in constricted spaces. From the seismic perspective, the strength and stiffness of a structure can be increased with very little increase in mass and this is highly desirable (Shrive 2006).

Compared to traditional materials such as wood, steel and concrete, composite materials such as fibre reinforced polymers (FRPs) have very good corrosion resistance. This leads to the exploration of new construction technologies focusing on using FRP materials as an alternative to the traditional steel, concrete, and wood materials (Awad et al. 2012). FRP composites are also being considered as a replacement to the conventional steel in reinforced concrete structures due to continuing drop in the cost of FRP composite materials. They are available in the form of rods, grids, sheets and winding strands. (Pendhari, Kant & Desai 2008).

The mechanism of composites reinforced with fibres is through the interaction between the fibres and the matrix. The interfacial bonds between the fibre and the matrix can be defined by the shear stress at the interface, which transfers stress between the fibre and the matrix surrounding the fibre (Lee & Won 2015). There are many types of fibres used as reinforcement for various matrices in composite materials. These include glass, carbon, aramid and Kevlar. Different fibres give different properties to the fabricated composite as well as its final cost of production. Some of the specific properties of these fibres as described by Hollaway (2010) are:

- Carbon fibres and FRP rods have good durability characteristics and are also very expensive.
- Aramid fibre and FRP rods are durable except under conditions such as static fatigue, UV radiation and acidic environment.
- Glass fibres are widely used due to its relatively lower cost but good mechanical properties. However, it is less durable than the other synthetic fibres as far as their alkaline resistance is concerned. Glass fibres are susceptible to the moisture extracting ions from the glass (corrosion of glass) and chemical attack and also degrade when exposed to UV radiation from the sun (Cromwell, Harries & Shahrooz 2011). They showed satisfactory characteristics in an acidic and freeze thaw environment.

However, there are important challenges that need to be addressed when using fibre reinforced composites. As their application has now been increased in the building industry, even expanding to repairing, strengthening and replacement of old structures, their reliability must be fully understood. One of the disadvantage highlighted by Hollaway (2010) is that FRP materials in general showed poor performance at high temperatures and therefore their use are avoided when fire resistance is required. At the service temperature of most structures, the binding resins are stable and perform as intended, but with increasing temperature, the resin breaks down and evaporates. A method used to improve this condition is by spraying fire retardants on the surface of the composite to provide some heat and fire resistance. However, further work is necessary in this field of study. Another drawback of using FRP composites is the susceptibility of the resin to ultraviolet light. The resin slowly becomes brittle when they are exposed to sunlight for long period of time. To overcome this, FRP must be protected from exposure to direct sunlight and this can easily be achieved indoors and with paint. Many studies have focused on the development of new resin formulations that will eliminate this problem (Shrive 2006).

There are uncertainties in designing fibre composite structures. Unlike steel which is a homogenous material with constant stiffness in all directions, the FRP composite material has different stiffness in different directions. They are generally anisotropic, brittle, low modulus, and are highly dependent on the properties of its components matrix and fibre. For example, the fibre composite member designed for tension cannot be loaded with torsion forces. Additionally, to design a fibre composite structure, the design process does not only include the shape or geometry design, the material itself should be included whereby the fibre plies should be considered in the design level and the overall geometry level of the structure. To overcome this, optimization methods can be applied as they have the advantages of offering the solution of geometry and materials design at the same stage (Awad et al. 2012).

The lack of information on the durability performance of FRP materials is recognized as being the primary impediment to expand the utilization of these materials in civil infrastructure applications. The definition of a durable material is "the ability of the material to resist cracking, oxidation, chemical degradation, delamination, wear, and effects of foreign object damage for a specified period of time, under the appropriate load conditions, under specified environmental conditions". Therefore, the performance of FRP composites for their intended use and environmental condition need to be considered before they are being applied. For instance, the combined effects of moisture or humidity and heat, also known as hygrothermal effect, are generally dominant in the degradation processes of FRP materials. Additionally, moisture absorption along with chemicals in solution may aggravate the degradation of FRP composites. Such condition is present when used with concrete due to the presence of salts and the high alkalinity of concrete pore water. Water absorption is also known to affect the bond between FRP and concrete, even more so than it does the FRP properties themselves. Moisture absorbed by the matrix of an FRP system can lead to the degradation of the matrix itself which consequently diminish its protection and stress transfer to the fibres. This phenomenon can be greatly magnified for incompatible fibre and resin (Cromwell, Harries & Shahrooz 2011).

2.2.3 Fibre reinforced composite for construction application

Fibres have been used to reinforce concrete for construction applications, such as shotcrete, tunnel lining, maritime structures, seismic structures and slabs on grade. Increased use of this material was observed in recent years as it can significantly increase the ductility of cementitious materials by improving their resistance to rupture and crack propagation. The fibre works by contributing to the increase in the ductility of cementitious composites through dominantly by the energy dispersion mechanism, which is related to pullout of the fibre from the matrix. By improving the bonding between the fibres and cementitious material, the developed composites will have higher strength and toughness. To study the effectiveness of fibre in this relationship, single-fibre pull-out tests can be performed to elucidate the mechanism of fibre reinforcement and to optimize the characteristics of the matrix and the fibres (Lee & Won 2015).

Because of their good engineering properties, an increase in the application of FRP composites has been seen in the construction industry over the last decade. Strengthening and rehabilitation of deteriorated infrastructures has recently brought the attention of civil engineers to the potential of composites as strengthening material. Initially, the applications of composites were in the form of rebars and structural shapes. Later, FRP composite laminates were introduced in the strengthening of concrete bridge girders by bonding them to the tension face of girder and also for retrofitting of concrete columns (Pendhari, Kant & Desai 2008).
Columns are fundamental in civil structures and to improve the state of this structural component is important for the safety of the building's occupants. Repair, retrofitting, and strengthening of damaged concrete columns using FRP composite wrapping or jacketing are increasingly becoming essential in civil infrastructures due to the high strength/stiffness to weight ratio, corrosion resistance, and ease of installation of FRPs. One of the parameters considered in designing the retrofits of columns using FRPs is the orientation of the fibre reinforcements. In practice, a column is usually subjected to an eccentric axial load, which can be divided into a co-axial compressive load and a bending moment. This requires an engineer to treat

columns as beam-columns. To support co-axial compressive loads, the optimal fibre orientation is in the hoop direction while the optimal direction for fibre orientation to support bending moment is in the axial direction. Therefore, fibre orientation is an important variable in the structural design of FRP wrapped concrete columns (Li et al. 2006).

Apart from retrofitting concrete, FRP can also be used to reinforce timber structures. FRPs are bonded using adhesives to repair and strengthen timber and engineered wood products. However, the lack of established standards and guidelines has impeded the use of FRP strengthening although it could make a better alternative than most traditional techniques. The commonly used adhesive for on-site repair jobs are epoxy based. Other types of adhesives are polyurethanes, polyesters, phenolics and aminoplastics. For timber and wood applications, this adhesive is found to be unsuitable as they are generally too rigid for bonding timber and there is no chemical bonding or suitable mechanical anchorage in wood. The bonding interface is found to be prone to failure due to the dimensional changes in the wood induced by moisture content variations, even for indoor applications. This has led to the formulations of epoxy developed specifically for use with wood. The selection of the adhesive for bonding of FRP to timber has to be undertaken with great care as it must be capable of bonding with both the FRP and timber and should have adequate strength. While many adhesive types have proven to provide satisfactory bonding performance when used in a controlled environment, it was found that two-part cold-cure epoxy adhesives are most suitable for on-site bonding as they demonstrate good gap-filling properties, are thixotropic and have low curing shrinkage. The advantages offered by this adhesive bonding, as well as the high strength and stiffness, light weight and good durability of FRP composite laminates have shown to be an effective and economical method for strengthening and repair of wooden structural members. It is important to note that careful surface preparation is essential in order to achieve good bond strength and durability (Schober et al. 2015).

FRP bars have been used to replace steel bars in concrete structures. However, the use of FRP bars is still a difficult challenge for engineers because of the massive

differences in the physical and mechanical properties between FRP and conventional steel. One of the drawbacks of FRP bars is the lower elastic modulus than that of steel bars and this leads to higher deflection and larger crack width in FRP bar-reinforced concrete beams that have an equivalent reinforcement ratio to steel-reinforced concrete beams. Glass fibre-reinforced polymer (GFRP) bars and aramid fibre-reinforced polymer (AFRP) bars have an elastic modulus that ranges between 35 and 50 GPa, while the elastic modulus of carbon fibre-reinforced polymer (CFRP) bars is between 120 and 150 GPa. Another major difference between steel and FRP bars is their failure behaviour. Steel are ductile up to failure while FRP fails in a brittle manner. In a reinforced concrete beam, brittle failure must be prevented and are avoided for FRP-reinforced concrete design by favouring failure by concrete crushing. This is usually avoided in steel-reinforced concrete design. Yang et al. (2012) have suggested the use of fibre reinforced concrete (FRC) as an alternative solution to overcome this problem. Steel fibres in concrete provide increased toughness, durability, and impact resistance, and control the initiation and growth of cracks. This application on steel-reinforced concrete design has been proven by many researchers to increase the ductility of the structural component. The author reported that the ductility indexes of GFRP beams with steel and synthetic fibres were approximately 70% and 80% higher, respectively, than the ductility index of GFRP beam with no fibres. It was summarised that the addition of fibres could be a possible method to overcome the low ductility of FRP bar-reinforced beams.

2.2.2 Natural fibres in building materials

The insulation of a building is crucial as it protects the inhabitants inside from extremely hot or cold climate. This relates to the efficient use of energy in residential housing and commercial offices in providing certain levels of comfort to the residents. Therefore, the study of thermal conductivity of building materials is important in order to better understand the insulation properties of these materials. In this study, a new approach has been evaluated regarding the fabrication of building materials, in particular wall panels, to reduce the heat transfer from outside temperature into the building while reducing the energy consumption by air

conditioners or heaters. Natural fibres based composite materials have shown promising potential as building materials as they have several attractive features such as low cost, less health hazards, are biodegradable and are derived from renewable resources. All these features will help towards environmental sustainability in the global building construction industry.

The approach that is being investigated in this study is to use sisal fibres in combination with traditional building materials as insulator in interior walls of building. The standard building materials currently in use have several disadvantages on the environment such as increase of waste disposal from construction sites and the hazardous emissions produced from fabrication works. Additionally, synthetic materials are relatively high cost, non-biodegradable and not recyclable.

Many previous investigations were carried out with the use of natural fibres as building materials and the outcomes show that they are comparable with other conventional building materials. However, it was highlighted that further studies are required to overcome the weakness of natural fibres.

Many researches have been carried out in this promising area. Benmansour et al. (2014) investigated a composite made of natural cement, sand and date palm fibre (DPF), and to evaluate the possibility of using it as insulating building materials. The authors revealed that the introduction of DPF reduces the thermal conductivity and compressive strength of the composite. If the content of DPF is lower than 15%, the composite satisfy both thermal and mechanical requirements for construction materials. The research concluded that the developed material is able to be used as wall structures.

Another study using DPF was carried out by Chikhi et al. (2013). The authors developed a new bio-composite made of DPF and gypsum. Biomaterials containing different DPF filler contents and two different sizes of DPF were prepared. The experiment results showed that the thermal conductivity of the gypsum based materials decreases with the increment of DPF contents. Mechanical properties such

as compressive and flexural strength of the bio-composites were also improved by adding adequate fibre contents. It is concluded that this new bio-composites have good thermal and mechanical properties and could be applied as thermal insulation for building materials.

Joseph Khedari et al. (2001) investigated a possible lightweight construction material composed of cement, sand and coconut and durian fibres. Thermal conductivity test results revealed that the addition of coconut and durian fibres reduced the composite's thermal conductivity. Meanwhile, the compressive strength and bulk density results showed that the material satisfied the basic requirements for construction materials and can be used in walls and roofs fabrications.

Agoudjil et al. (2011) studied the thermophysical, chemical and dielectric properties of three types of date palm wood (DPW). Their results from Scanning Electron Microscopy (SEM) revealed that the surfaces of the samples are irregular with many filaments, impurities, cells and pores. Thermal conductivity test results show this material has relatively good insulating properties and is a good candidate for the development of efficient and safe insulating materials.

2.3 Sisal fibre as reinforcement in composites

In this study, sisal fibre is used as natural fibre reinforcement for building materials. This section compiles the findings and conclusions of researchers on the properties of sisal fibres that are relevant for civil engineering applications.

2.3.1 Properties of sisal fibres

Sisal fibre is extracted from the leaves of sisal (Agave sisalana), which is widely grown in Tanzania, Brazil and other tropical countries with an annual yield of 4.5 million tons (Li, Mai & Ye 2000). Sisal fibres are composed of three main constituents: cellulose, hemicellulose, and lignin. Cellulose is the highest constituent

but its portion varies in different areas. The physical properties of sisal fibres include a density range of 1400~1450 kg/m3, and fibre diameter range of 100~300 μm. Its tensile strength ranges from 400~700 MPa, with the tensile modulus from 7~22 GPa.

The tensile and fatigue properties of sisal fibres from Algeria, with approximately 250μm of diameter and 0.8-1 m of length were tested by Belaadi et al. (2013) tested. Over 15 samples were measured and it is found that the strength of the fibres are higher (9N~22N) than previous figures in open literature. The S-N curves results received from the fatigue testing can be used to predict the fatigue and structural integrity behaviour of sisal reinforced polymer composites, and may assist in the design of this natural fibre. Belaadi et al. (2014) investigated over 40 sisal fibres samples on their mechanical properties statistical model versus fibre diameters. A Weibull distribution statistics were used to estimate their tensile and modulus properties and was compared with experimental data. At the gauge length of 20 mm, high tensile strength / modulus were obtained from the finest fibre diameters, approximately 140 μm. The authors also used FTIR and DSC results to observe its cellulose, lignin, and hemicellulose structure.

Another test on the tensile properties of sisal fibres were conducted by Silva, Chawla and de Toledo (2008). Four different gauge lengths (10, 20, 30, 40 mm) were used in the study. The results showed that the tensile strength and the tensile modulus (approximately 18 GPa) was not impacted by the gauge length. The fracture mode through SEM images was found to be resulted by delamination between primary and tertiary wall, and between fibre-cells. The authors studied the sisal fibre's fatigue behaviours through tensile experiments. The sisal fibres were tested at stress between 80 ~ 400 MPa. It is found that fibres subjected to a ratio of 0.5 of ultimate tensile strength have survived 10^6 cycles, and failed at ratio between 0.6 to 0.8 and fatigue lives between 10^3 and 10^6 cycles. No significant stress-strain hysteresis was found during fatigue.

Martin et al. (2010) analyzed raw and defatted sisal fibre's thermal properties through TG and DSC analysis. The DSC curves in inert atmosphere show that the

sisal fibres have different peaks for each constituent (cellulose, hemicellulose and lignin). However, in air atmosphere, there are two exothermic peaks for all constituents. TGA results showed that cellulose and hemicellulose degraded at lower temperatures for treated sisal fibres due to removal of lignin. The thermal degradation of sisal fibre and its constituents is similar to other natural fibres such as jute and hemp.

2.3.2 Various fibre treatments on sisal fibres

In order to use sisal fibre to reinforce polymers, some fibre modification is necessary. The commonly used methods include treatment using benzol/alcohol, alkali, acetylate, silane, thermal and combination of two or more methods. The treatment of sisal fibres will improve its interfacial bond with polymers and therefore, resulting in good reinforcing effect on the polymer matrices.

Zhou, Cheng and Jiang (2014) used silane coupling agents to modify sisal fibre and investigated the chemical reaction between sisal fibre and silane. Through SEM, FTIR, TG, DSC, TG/MS, it is found there is a layer composed of siloxane and polysiloxane on the sisal fibre surface. Chemical bonds were formed between sisal fibre and silane agent. These results indicate that silane changes the surface topography and chemical structure of sisal fibre. This leads to better cohesion with the polymer matrix to produce sisal-fibre reinforced polymer composites.

Another treatment widely used to modify natural fibres is by soaking them in alkali, known as alkalization. Barreto et al. (2011) modified sisal fibres using alkali solution NaOH at 5% and 10% concentration and bleached them with sodium hyplochlorite NaClO/H2O (1:1) at 60-75 degrees, and then combined with phenolic matrix derived from cashew nut shell liquid (CNSL) to make a biocomposite. It is found that the alkali chemical treatment increased the crystalline fraction and improved the thermal stability of sisal fibres. Additionally, from the morphological study through SEM, it was found that this chemical treatment exposed the cellulose component of the fibre

and increased its superficial area. This provided better cohesion between the sisal fibres and the phenolic matrix material.

Alkalizations using NaOH was also used by Mohan and Kanny (2012) in combination with clay to chemically treat sisal fibre in order to improve the fibre-matrix compatibility and interfacial strength with the matrix. Structure and morphology study through FTIR, EDX and XRD revealed that the treated sisal fibre has a dissolution of amorphous lignin phase and crystalline fraction of 76%, and with 20% clays in the treated sisal fibre in weight. Mechanical properties such as tensile strength, modulus and strain are increased compared to the untreated sisal fibre by 14~18%, and 10% increase in dynamic stiffness. The improvement in glass transition temperature Tg was also observed in treated sisal fibre composites.

Kim and Netravali (2010) mercerized sisal fibres under tension and no tension, in order to improve their tensile properties and interfacial connection with soy protein matrix. The sisal fibres were treated in 2 M NaOH solution under different tensions (from 0g to 100g weight per fibre) for 2h, and then soaked into procured Soy Protein Concentrate (SPC) resin to fabricate the composites. The composite samples were cured at 120℃. The composite's fracture stress and stiffness were found to increase up to 12.2% and 36.2%, compared to unmercerized sisal fibre reinforced composites. Morphology study through SEM on the composite's fracture surfaces indicated that there is better adhesion between sisal fibre and soy matrix after the mercerization treatment.

Rong et al. (2001) investigated the effects of fibre treatments on mechanical properties of unidirectional sisal fibre reinforced epoxy composites. Many treatment methods such as alkalization, acetylation, cyanoethylation, silane coupling agent, and hearting were applied to modify sisal fibre's structures. Through FTIR, XRD, and SEM investigations, it is found that the adhesion between matrix epoxy and sisal fibres was improved. This improved adhesion between matrix and fibre resulted in better mechanical properties, i.e. higher tensile strength and modulus and higher flexural stiffness in treated sisal fibre composites. Among those chemical treatment

methods, AT (Alkali- Treated) + HT (Heat- Treated) treatment seemed to have the best effect in improving flexural stiffness.

2.4 Mechanical properties of natural fibre composites

The mechanical properties of a material are important benchmarks to evaluate its capability to be used in civil structures. The bending, compressive and tensile behaviours are the most studied properties in the research of composite materials.

2.4.1 Sisal fibre as reinforcement in polymers

Ramesh, Palanikumar and Reddy (2013) fabricated hybrid fibre composites – polyester reinforced by sisal fibre, jute fibre and glass fibre, and evaluated their mechanical properties such as tensile strength, flexural strength and impact strength. It is found that the sisal and jute fibres are able to support glass fibres as reinforcement for polyester and improved its flexural and tensile strength. SEM results also revealed that the breakage occurred in the sisal/jute fibres.

Short sisal fibres were used by Antich et al. (2006) to reinforce high impact polystyrene (HIPS) mechanical tests such as tensile and fracture tests were carried out on the composite samples. In the uniaxial tensile test, it was found that for 25% sisal volume, the composite showed an increase in Young's modulus (from 1.91 GPa to 2.51GPa), but a decrease in the tensile strength (from 21.66 MPa to 11.52 MPa) and elongation break rate (3.96% to 0.76%). On the other hand, the composite's impact strength decreased from 2.97 kJ/m2 (0% sisal) to 1.67 kJ/m2 (25% sisal). Through morphologic study, the decrease in mechanical properties is observed to be caused by poor adhesion between HIPS matrix and sisal fibre, and therefore the restriction of matrix yielding.

Milanese, Cioffi and Voorwald (2012) fabricated woven sisal fabrics/phenolic resin composites using compression moulding, and tested its tensile and flexural strength.

Experimental results showed that with the introduction of sisal fibre, the phenolic resin's tensile strength increased from 4.9 MPa to 25.2 MPa, with the elongation yield from 0.14% to 7.9%. This demonstrates the change that the material experienced, from brittle to ductile. In the flexural experiment, the phenolic resin's flexural strength increased from 8.6 MPa to 10.7 MPa (sisal without heat treatment), and 11.2 MPa (heat treated sisal), with the deflection increased from 3.0 mm to 14.0 mm and 17.5 mm, respectively.

Belaadi et al. (2014) studied the fatigue property of sisal fibre reinforced polyester bio-composite. The samples were fabricated to create fibre directions laminates with [0/90] sequence. Three-point bending static and cyclic tests (frequency 1.5 Hz) were carried out in the study. The results revealed that failure occurred after the first few cycles for high loading levels, while for low loading levels, variance fracture is partial even after 1 million cycles.

Towo and Ansell (2008) used 0.06 M NaOH to treat sisal fibres which were used to reinforce polyester and epoxy resins in hot press to fabricate two different composite samples. Fatigue tensile tests under loading levels of 75%, 60%, 50% and 35% were performed to evaluate the fatigue behaviours of the thermoset-sisal fibre composites. The results revealed that epoxy matrix composite had a longer fatigue life than polyester matrix composite. DMTA results showed that the composite's glass transition temperature (Tg) was lowered after the NaOH treatment of sisal fibres. Static tensile test results showed an improvement on both polyester and epoxy matrix composites after the NaOH treatment. It was concluded that the sisal fibre-thermosets composite's fatigue strengths are suitably high for many commercial applications.

2.4.2 Parameters effecting the mechanical properties of natural fibre composites

There are many factors that need to be considered in order to fabricate composites meeting specified physical, mechanical, thermal or acoustic properties. Many

researchers have attempted to study the effects of these parameters on the outcome of the fabricated composite samples.

The mechanical properties of sisal fibre reinforced high-density polyethylene (HDPE) composite were studied by Zhao, Li and Bai (2014). The critical parameters such as fibre content, interfacial compatibilization and manufacturing process were evaluated. The increment of fibre content and maleic anhydride grafted HDPE (MAPE) which has a better interfacial compatibilization was found to improve the composite's mechanical properties. A pre-impregnation process with compatibilzer MAPE is found to be better than the simultaneous blending. Meanwhile, the general Power-Law equation fits the composite's creep curve quite well and is able to predict the composite's creep behaviour.

Megiatto et al. (2009) studied the optimized process parameters for manufacturing thermoset phenolic composites reinforced with sisal fibres. The criterion is to control the vaporization of water release during the curing reaction of thermosets. The results showed that higher pressure before the phenolic matrix's gel point leads to a composite with higher performance. SEM images revealed there is less void in the matrix with the application of higher molding pressure during curing. Meanwhile a better filling of fibre channels reduced the water molecules diffusion.

Fung et al. (2003) applied a pre-impregnation technique for the injection moulding of sisal fibre reinforced polypropylene composites. Through thermal analysis, it is found that the composite can be processed at a lower barrel temperature after pre-impregnation treatment, and a significant thermal degradation of sisal fibre can be avoided. This process also resulted in lighter colour and no odour.

Sangthong, Pongprayoon and Yanumet (2009) modified sisal fibres using poly(methyl methacrylate, MMA) film's admicellar polymerization on the fibre surface to improve the interfacial connection between sisal fibres and the unsaturated polyester matrix. The composite's mechanical properties such as tensile strength/modulus, flexural strength/modulus, impact strength and stiffness were

tested and compared under different MMA portion. It is observed generally that the composite's mechanical property increased alongside the increment of MMA amount, and the best mechanical properties is obtained at 30 vol% sisal fibre and MMA amount of 0.075% v/v. SEM results on the fracture surface also showed that the bonding is stronger after MMA treatment compared to the untreated fibres, and the failure tend to occur due to fibre breakage rather than interfacial debonding.

2.4.3 Compressive strength of walls with natural fibres

Many innovations on building materials using some form of natural fibres or recyclable materials have been widely experimented. This includes the incorporation of natural fibres as reinforcements or fillers in panels and walls as part of an effort to promote sustainability in the construction industry. The compressive strength of these structures needs to be thoroughly evaluated before they can be promoted for commercial use. These types of study have been undertaken by a few researchers.

First and foremost, it can be highlighted that the construction industry continuously seeks for improved building materials that are superior in performance but are cost optimized. La Rosa et al. (2014) have studied the environmental impacts of composite materials for building applications. Their aim was to manufacture materials with good structural properties, low environmental impacts and low thermal conductivity. The study suggests that materials with low thermal transmittance uses less material for wall construction, but the environmental impacts evaluated in the manufacture phase is highly influenced by the type of material used than on their weight. Less material means lighter walls and roofs which are easy to install and can reduce construction cycle time by one to four weeks. However, the environmental impacts are very high due to the epoxy resin used but minor energy is required both for material transportation and installation. Therefore, one of the ways to produce lighter materials is by incorporating natural fibres or agricultural waste into the fabrication of building materials. Natural fibres are known to have good

strength-to-weight ratio and this may produce lighter materials with satisfactory mechanical properties.

Wu et al. (2015) have introduced a new-type of building block using shale and waste as raw materials. These fired hollow blocks were tested for their mechanical and insulating properties. It was found that the strength grade of the block and special mortar meet the strength requirement of materials used in the construction of bearing wall. It was also observed that the failure mechanism of the walls showed ductile behaviour, satisfying the deformation condition and seismic capacity of building requirements. The authors concluded that the blocks from green materials are possible substitutes to the traditional ones currently in use today.

The hazardous use of asbestos has pushed researchers and engineers to find safer alternatives for this material in the building industry. Lertwattanaruk and Suntijitto (2015) have suggested the use of natural fiber cement sheets as an alternative, offering the increase in value of reused materials from agricultural manufacturing. The study was performed using cement mortar containing coconut coir fiber and oil palm fiber, fabricated into cement sheets. From the experiments, the results yielded comparable effects in the physical and thermal properties. The natural fibre cement sheets was found to have increase in apparent porosity and a decrease in bulk density. With the addition of fibressoil- the mix proportions, the composite showed lower compressive and flexural strength. However, the values obtained was still acceptable by ASTM standards for fiber cement sheet and roofing.

Another study was performed by Khedari, Watsanasathaporn and Hirunlabh (2005) on soil-cement block, whereby coconut fibres were introduced into the mixture. The special requirement was to maintain the block's natural color, therefore, a preliminary study was conducted to determine the maximum percentage of cement that could be used without leading to a significant color change. However, it was found that the compressive strength of the composite was only 3.88 MPa. This is considered low and it was suggested that the blocks could only be used to build non-

load bearing concrete masonry units (2.45 MPa) as they could not support loads from floors and roof.

Benmansour et al. (2014) have studied the possibility of using natural mortar reinforced with date palm fibres as insulating materials in buildings. The same outcome was observed as previous literatures, whereby the increase in fiber content reduces the mechanical strength of the mortar. However, at low concentration of wood (5%, 10%, and 15%), the mechanical and thermal performance of the composites are found to be satisfactory as structural and bearing insulators.

2.5 Thermal conductivity

Thermal conductivity is the ability of a material to transfer heat. Its testing method is according to ASTM C518. Many research papers have highlighted that natural fibres can decrease a composite's thermal conductivity and therefore, they are a viable material to be used as an insulator in a building.

2.5.1 Thermal conductivity of natural fibre composites

There are a few methods that can be used to evaluate the thermal conductivity of a material. The common evaluation is by expressing the coefficient of thermal conductivity which is expressed as W/mK. Thermal conductivity is defined as the quantity of heat transmitted through a unit thickness of a material, in a direction normal to a surface of unit area, due to a unit temperature gradient under steady state conditions. This is mainly used to evaluate and compare how easily a material transfer heat, therefore, a higher thermal conductivity shows poor heat insulating property and vice versa. The K values for some materials are tabulated in Table 2.1.

Table 2.1: Coefficient of thermal conductivity of different materials

Material	Coefficient of Thermal Conductivity, K (W/mK)	Reference
Air	0.026	(Liu et al. 2012a)
Sisal fibres	0.042	(Neira & Marinho 2009)
Glass fibres	0.038	(Neira & Marinho 2009)
Typha angustifolia fibre	0.137	(Ramanaiah, Ratna Prasad & Chandra Reddy 2011)
Cured polyester resin	0.432	(Ramanaiah, Ratna Prasad & Chandra Reddy 2011)
Typha angustifolia fibre-polyester composites	0.32 to 0.39	(Ramanaiah, Ratna Prasad & Chandra Reddy 2011)
Bamboo fibre-polyester composites	0.185 to 0.211	(Mounika et al. 2012)
Glass fibre-polyester composite	0.223	(Mounika et al. 2012)
Borassus seed shoot fibre-polyester composite	0. 176 to 0.193	(Mohapatra, Mishra & Choudhury 2015)
Coconut husk and bagasse insulation board	0.046 to 0.068	(Panyakaew & Fotios 2011)
Coir based soil–cement block	0.651	(Khedari, Watsanasathaporn & Hirunlabh 2005)
Clay bricks	0.77	(Lymath 2015)
Glasswool	0.04	(Lymath 2015)
Concrete blocks	1.13	(Lymath 2015)
Plaster	0.50	(Lymath 2015)

To achieve the objective of this study, a low thermal conductivity of the developed materials is desirable. Many researchers have studied the thermal conductivity of a variety of materials and composites in order to obtain optimum energy saving from the use of proper materials to serve their intended use.

Liu et al. (2012a) had studied the effect of lumen (the hollow part of fibre bundle) size on the effective transverse thermal conductivity of unidirectional natural fibre composites. Through computer modelling, the unidirectional natural fibre composites are modeled as a two-dimensional square arrayed pipe filament (SAPF). Thermal-electrical analogy technique is used to evaluate the effective transverse thermal conductivity of this model composite. It was concluded that, amongst others, the dimensionless effective transverse thermal conductivity, K_t^+ of natural fibre composites are dependent on the geometrical ratio α, which is the ratio of lumen radius and fibre radius; the thermal conductivity ratio $\beta = K_f/K_m$ (where f and m represents fibre and matrix, respectively); and fibre volume fraction. Also, the lumen size ratio α affects the effective transverse thermal conductivity of natural fibres composites more greatly as compared to conventional fibre composites.

Further testing was performed by Liu et al. (2012b) on the effect of the microstructure of natural fibre on the transverse thermal conductivity of unidirectional epoxy composite reinforced with abaca and bamboo fibres using resin transfer molding (RTM) technique. The results indicated that the transverse thermal conductivity increased with increasing bamboo fibre but decreased with abaca fibres. In comparison to bamboo fibre, abaca fibre presents higher crystallinity in the directions of along and cross fibre. From the microstructure and theoretical analysis, it was found that the lumen structure plays a greater role rather than the crystal structures and chemical compounds on the transverse thermal conductivity of unidirectional composites. This information is useful for further development and design of natural fibre reinforced composites with better thermal insulation property.

A study by Ramanaiah, Ratna Prasad and Chandra Reddy (2011) on the thermal conductivity of typha angustifolia natural fibre reinforced polyester composites have found to decrease with increase in fibre content. The authors justified this behaviour of the composite due to the lower thermal conductivity of the fibre being loaded in the matrix. They confirmed that the values of thermal conductivities obtained from empirical models were in good agreement with the experimentally measured values. It was concluded that the composites under study have good insulating properties,

suitable for applications such as electronic packages, insulation boards, automobile parts, building construction, and other uses.

The effect of the stalk particle size and the epoxy/corn stalk particle ratio on the thermal and mechanical properties of the composites prepared were evaluated by Binici, Aksogan and Demirhan (2016). These properties were compared with the commercially available bio-based insulation materials. The study suggested that it was possible to prepare bio-based composite materials with low heat transfer coefficients. The developed composites had thermal conductivity coefficients lower than 0.1 W/mK, meeting the requirement set by TS 805 EN 601 in order to qualify a material as a thermal insulator. The authors were very positive on the impact of this sustainable filler from organic origin, as farmers in rural areas can reuse this waste material for the preparation of commercially feasible and satisfactory insulation material which will finally lead to energy savings.

Wang and Qin (2015) had studied the effects of interface or interphase on micro- and macro-thermal behaviors of square-pattern unidirectional fibre-reinforced composites. Interesting findings show that, for both V_f =10% and V_f =30%, the overall thermal property of the composite increases with the increase of interface thickness for carbon and glass fibres, but decreases for hemp fibre. It was noted that the increase of interface thickness will increase the volume fraction of the fibre and interface region, significantly affecting the overall thermal property of the composite. For carbon and glass fibres, both interface and fibre materials have greater thermal conductivity than that of the matrix. Therefore, the increase in the volume fraction of the special element resulted in greater thermal conductivity of the composite. In contrast, for the hemp fibre, the increase in the volume fraction of the special element produces lower thermal conductivity of the composite because both interface and fibre materials have lower thermal conductivity than that of the matrix. This provides good explanation on why a higher fibre volume fraction can uncertainly result in either lower or higher effective thermal conductivity of the composite.

Fongang et al. (2015) utilized sawdust, a by-product from the wood industries, abundantly available in the tropical areas of the world, to produce low cost, ecological and sustainable lightweight composite for thermal insulation. The thermal conductivity of the sawdust is 0.10 ± 0.02 W/mK and posses lower energy thus inappropriate for the production of good pellets. The sawdust was successfully bound with metakaolin based geopolymer paste. The developed composite had a sponge-like structure with a homogeneously distributed pore network, low density and low thermal conductivity. The properties of the material obtained from the study include a density of approximately 0.79 g/cm^3, bi-axial four-point flexural strength of approximately 4 MPa and thermal conductivity between 0.2 and 0.3 W/mK. This classifies the geopolymer–wood fibre composites as promising clean and lightweight insulating materials. The movement of heat across the matrix indicated a "macro transport" mechanism based on the pores network and the microstructure approximated by a spatial periodic geometry. This mechanism involves the movement of heat through a multicomponent structure including thermo-diffusion and diffusional thermal effects.

It was reported by La Rosa et al. (2014) that it is important to select insulation materials with low thermal conductivity as it enables the application of relatively thin building envelopes with high thermal resistance (m^2 K/W) and low thermal transmittance U (W/m^{2}K). A study performed by Kumar and Suman (2013) attempted to observe the behaviour of different insulation materials on conventional walls and roofs used in majority of the buildings. It was highlighted that conventional roof and wall sections have high overall thermal transmittance and by adding insulation in these sections, the U factor reduces. U value is also known as thermal transmittance which represents the rate of transfer of heat through a structure divided by the difference in temperature across that structure. This structure can be a single material or a composite. The U value is higher for a better-insulated structure (Lymath 2015). Kumar and Suman (2013) further explained the effect of the U-value of the materials. The authors found that with lower U-value, the cooling load of building will also be lower and vice-versa. Therefore, the load on mechanical systems will be lower for building sections with low U-value. The study uses

guidelines from The Energy Conservation Building Code (ECBC) of India. Walls insulated by various materials with thickness that satisfies the U value as per ECBC was reported. Elastospray, PUF, EPS, Fibre glass and foam concrete required thickness of 50 mm, 60 mm, 70 mm, 80 mm and 150 mm, respectively, to satisfy the ECBC requirements. It was concluded that the results of their study could assist designers, architects and engineers to design more energy efficient buildings satisfying the ECBC requirements.

2.5.2 Improvement of thermal properties of natural fibres

In comparison to synthetic fibres, natural fibres have shown less durability in high thermal exposure. Many efforts have been undertaken to improve the performance of natural fibre composites in this type of condition in order to expand its use for various applications.

According to Elenga et al. (2013), raffia fibres treated with sodium hydroxide (NaOH) had shown higher resistance to thermal degradation. The test was performed using Thermo Gravimetric Analysis (TGA) and t was found that the thermal degradation onsets of the raw, 2.5%, 5%, and 10% NaOH-treated fibres were 256 °C, 272 °C, 278 °C, and 250 °C, respectively. The author explained that the effect of the alkali treatment based on its concentration on the fibre was basically due to the degree of removal of hemicellulose, which is the least stable of the three major constituents of the fibre. At a much higher NaOH concentration, which is at 10%, destabilization of the native cellulose may have decreased the thermal stability of the raffia fibres. Generally, the raw raffia fibre is considered to have a higher onset from the average value reported for plant fibres which is approximately 219 °C.

Apart from fibre treatment, the addition of additives into a composite system during fabrication process is also another method for increasing the thermal stability of natural fibre based composites. Shukor et al. (2014) have used ammonium polyphosphate (APP) to provide flame retardancy and to increase thermal stability and mechanical properties of alkali treated kenaf fibre filled PLA biocomposites. All

three properties were found to be significantly affected by the addition of APP. From the thermo gravimetric analysis (TGA), the increment of APP content demonstrated higher residual char of PLA composites at final temperature. However, this has compromised the mechanical properties of the composite due to the poor compatibility between fibre and PLA matrix. Overall, it was reported that the intumescent flame retardant system containing treated kenaf and APP showed high efficiency in enhancing flame retardancy of PLA. It was also noted that alkali treatment increased the thermal stability of PLA biocomposites and decreased the residual char at high temperature.

Kabir et al. (2011) had also performed TGA on hemp fibres. The untreated hemp fibre started degrading at 200°C. Its hemicellulose and lignin degradation was reported at 270°C while the 4, 6, 8 and 10% NaOH treated fibres' were at 289, 287, 290 and 288°C, respectively. This indicates that the alkali treatment resulted in higher thermal stability of the fibre. The authors attributed this to the reduction in hemicelluloses and lignin content of the fibre, making it fore thermally stable. Furthermore, the removal of these components may have caused the fibres to become more hydrophobic and enhanced the better possibility to adhere with the matrix. The authors had also treated the same batch of untreated and treated hemp fibres with acetyl. Through this acetylation treatment, the fibres undergo further purification making them more thermally stable than the untreated and alkalized fibres, with higher degradation temperatures of lignin, hemicelluloses and cellulosic constituents for acetylated fibres. The weight loss variations as a function of temperature were also minimized after acetylation treatment.

A comparative study was performed by Lu and Oza (2013) on hemp-high density polyethylene (HDPE) composites treated with silane and sodium hydroxide (NaOH). It was observed that the thermal stability of the composites improved drastically after fibre chemical modification using both methods. However, amongst the two methods, silane treatment outperforms NaOH treatment at the same fibre volume fractions. The author attributed this to the various type of reactions that occur at the surface of silane treated hemp fibre, such as hydrolysis, condensation, hydrogen

bonding and covalent bond formation. The silanol molecules react with the hydroxyl group of hemp, resulting in formation of strong covalent bonds to the cell wall of the fibre. Simultaneously, the vinyl group of the silane molecule also couples with the thermoplastic matrix which resulted in increased physical compatibility and strength of bonding between the silane and the matrix. In short, the silane acts as a bridge, connecting and holding the fibre and matrix together. This in turn increases the thermal stability of the resultant composites.

The use of enzyme to improve the surface and thermal characterization of natural fibres have been undertaken by George, Mussone and Bressler (2014). These enzymes have reportedly succeeded in removing the hygroscopic pectic and hemicellulose material producing a more homogenous fibre surfaces with improved thermal properties. From the SEM micrographs, the removal of these components resulted in an increase in individual bundle exposure. Also, in terms of the thermal stability of the natural fibres, the enzymetic treatment has selectively removed the least stable pectic and hemicellulosic content. Additionally, the authors found that the ultrastruture of flax fibres results in a more efficient enzymatic treatment compared to the hemp fibres making it a better option for reinforcing polymeric matrices.

Using sulfonic acid derivatives can also be effectively used to enhance the surface and thermal properties of natural fibres for composite applications. Another study by George, Mussone and Bressler (2015) using hemp fibres treated with this acid showed improved thermal properties and reduced surface polarity as a result of grafting of these acid residues that contain bulky benzene rings. These key observations were obtained by the production of a more tightly bonded rigid structure and capping of hydroxyl groups on the surface. One important finding from the study was that the substitution pattern on the benzene ring influences the effectiveness of the chemical during reaction with the surface hydroxyl groups of the fibre. In addition, less sterically hindered aniline-2-sulfonic acid treated fibres displayed better results when compared to 4-aminotoluene-3-sulfonic acid treated hemp fibres.

2.5.3 Thermal insulation of wall panels in building construction

One of the characteristics that need to be addressed for wall panels in buildings is its ability to provide good heat insulation for the comfort of its occupants. This means that the temperature inside the building can be controlled and maintained at a desired level without heat transfer occurring either from indoors to outdoors or vice versa. Stazi et al. (2015) had studied some parameters involved in providing high thermal insulation in buildings. The study proposed a combination of dynamic strategies which includes daily natural ventilation, inner mass of wall, and vented external wall. It was found that this proposal ensures optimum summer comfort, winter and summer energy saving and a lower global cost despite the higher initial investment. So, in this section, literatures on the contribution of interior walls on the thermal insulation of buildings are reviewed and summarised.

A study on glass fibreboard used for interior building envelope was conducted by Cao et al. (2015). It was reported that the effective thermal conductivity decreases with the increasing porosity at a near-linear rate. Their results were positive, showing that thermal conductivity of the glass fibre board is lower than normal insulation materials, therefore is suitable for use as interior building envelope insulation. The study was also conducted on internal floor of buildings. The energy consumption simulations of a typical residential building demonstrated that both the interior walls and the floor insulated with glass fibreboards resulted in reduced central heating energy consumptions. As for the effect of locations, in their case, Harbin and Beijing, the energy saving potentials with the interior wall insulation were slightly higher in Harbin than that in Beijing with the same insulation thickness. Conversely, the energy saving potentials with the floor insulation were similar for the two cities. Another important finding was that the potential of energy saving increased with thicker glass fibre insulation. However, the thickness should be reasonably controlled due to economical consideration. The author recommended a maximum insulation thickness of about 20 mm, for the energy savings increased slowly for thickness above 20 mm.

Another type of panels used for thermal insulation in the building construction industry is the Vacuum Insulation Panels, or simply known as VIPs Alam, Singh and Limbachiya (2011). This high performance thermal insulation has a large potential in reducing the CO_2 foot prints of buildings (1.56 kg CO_2 m^{-2} a^{-1}) and in conforming to stringent energy standards. VIP is highly attractive due to its ability of using minimal existing space. However, the constraints for the adoption of VIPs are due to their disadvantages which include easily damaged during installation and development, uncertain useful life time, thermal bridging and high cost. Researchers are conducted to improve the use of VIPs. One of the methods is by replacing conventional aluminium and metalized PET with PET multiple sheets coated with silicon. However, this will lead to higher VIP cost due to high market prices of fumed silica core material. To overcome this, the use of fumed silica–perlite composite as the core material for VIP was introduced. This, however, might result into some thermal resistance being sacrificed. Another potential for VIP improvement is my modifying open-celled polystyrene with a suitable filler material to provide low out gassing properties. The author noted that the challenge for using this method is to determine the best type, amount and distribution of filler material in the composite. These optimum conditions are required to achieve and maintain a suitable vacuum level inside the core to result in design thermal conductivity values with intended useful life of 100 years or more.

Other researchers have also tried to explore the possibility of using sustainable materials to provide insulation in buildings. Some have experimented with recycled materials while others have used natural fibres as reinforcement or fillers in composite materials. This was extensively reviewed by Asdrubali, D'Alessandro and Schiavoni (2015). The authors shared that the current thermo-acoustic insulators dominating the market includes mineral wool, extruded and expanded polystyrene. Sustainable materials are needed to construct more environmentally friendly buildings. This includes using natural sources such as residues of agricultural production and processing industries as well as recycled products or industrial plants byproducts. The sustainability of these insulation materials are related to the

availability of their components since the use of local materials lead to a reduction of economic and environmental impacts. The authors also emphasized that the production of insulators made of natural materials should be focused on using residues and byproducts of the agricultural sector instead of conflicting with the plantation and harvesting of food crops. By using these sustainable materials, it is expected to reduce the use of oil-based and non-renewable sources.

Wu et al. (2015) had introduced a new-type block using shale and waste as raw materials. The authors reported that the heat conductivity coefficient of the fabricated blocks obtained from the thermal test shows remarkable self-insulation characteristics of the wall. Lertwattanaruk and Suntijitto (2015) studied the properties of natural fibre cement materials containing coconut coir and oil palm fibres for residential building applications. Based on the authors, these natural fibre cement sheets offer an alternative to products such as asbestos. These sheets could also increase the value of reused materials from agricultural manufacturing. Based on their results, natural fibre cement sheets made of cement mortar containing coconut coir fibre and oil palm fibre yielded comparable effects in terms of their physical and thermal properties. This was achieved by optimizing the heat insulation properties of the material whereby the content of coconut coir fibre or oil palm fibre were added up to 10% weight ratio to the binder. The fibre should also be treated in order to remove some chemical compounds such as inorganic compounds which may affect the quality and durability of cement products in the long term. They observed that the addition of coconut coir fibre and oil palm fibre into the mix proportion lowered the bulk density of the cement sheets and successfully reduced the material's thermal conductivity, which provided effective heat insulation. Furthermore, the heat conductivity was relatively low compared to other fibre cement sheets in the market. They concluded that the natural fibre cement sheets can be applied for both naturally ventilated and air-conditioned residential buildings for better energy efficiency.

A different type of insulated wall system was presented by Alavez-Ramirez et al. (2012) which uses coconut fibre filled ferrocement on sandwich type wall panels.

The coconut fibre is identified as an ecologically friendly and sustainable option to build roofs and panels in hot tropical weather. The study reported that as fibre loading content of coconut filled ferrocement panels is raised, thermal conductivity is reduced down to a certain limit. These panels showed good performance as insulating material for building in southern Mexico and are competitive with other materials such as lightweight concrete brick, hollow concrete block and red clay brick panel walls. Another study using coconut fibre was performed by Khedari, Watsanasathaporn and Hirunlabh (2005). In this study, the coconut fibre was used as an admixture on soil-cement blocks with the target of reducing the thermal conductivity and weight of the blocks. It was reported that he optimum volume ratio of soil:cement:sand and fibre weight (kg) is 5.75:1.25:2 and 0.8 kg coconut coir. The average properties of the natural fibre blocks show a thermal conductivity of 0.6510 W/m K, compressive strength of 3.88 MPa, mass of 4.85 kg and bulk density of 1586.77 kg/m^3. They compared these values to commercial soil–cement block and found that the samples had significantly lower thermal conductivity and mass, 54% and 750 g, respectively. The weight of coconut coir soil–cement is approximately 13% lower than commercial soil–cement block making them convenient to deliver. Additionally, the low thermal conductivity of the blocks will help to prevent heat transfer into building and consequently contributes to energy saving efforts. Benmansour et al. (2014) have also introduced a more environmental friendly insulating material for building applications. Their study uses date palm fibres to reinforce natural mortar. From their observation, the increase of date palm fibre content has led to lower weight of the mortar composites. This was achieved by decreasing the overall density of the composites which results in higher insulating capacity of mortar. However, by increasing the fibre content of the composites, the mechanical properties were reduced. This requires an optimum fibre volume fraction to achieve a balance between the mechanical and thermal properties of the mortar composites. Based on their analysis, the authors found the optimum ratio of date palm fibres component to be in the range of 5–15%.

Chikhi et al. (2013) developed a new bio-composite material as thermal insulators in buildings. The fibres used are from date palms. From their experimental

investigations, the thermal conductivity increases with the introduction of date palm fibres. Additionally, it was found that the composite's compressive and flexural strength was improved by adding the optimum amount of fibre content. According to a research paper by Binici et al. (2007), natural fibre reinforced mud bricks had better thermal isolation and mechanical properties which was confirmed to ASTM and Turkish standards. The testing results showed a higher compressive strength and heat conductivity than concrete brick.

Korjenic et al. (2011) used jute, flax, and hemp to develop a new insulating material for buildings. The thermal conductivity test results of the composite samples revealed that natural fibre composites are likely to become a suitable alternative to commonly used boards. Panyakaew and Fotios (2011) made a low density thermal insulation board from coconut husk and bagasse. It is found that the bagasse insulation board has a low density of 350 Kg/m3 and a thermal conductivity values from 0.046 to 0.068 W/mK and are comparable to cellulose fibres and mineral wool.

2.5.4 Effect of moisture on the thermal conductivity of materials

There are many factors that need to be considered for an insulating material to be considered feasible and usable for actual wall panels in building constructions. (Asdrubali, D'Alessandro & Schiavoni 2015) had performed a life-cycle assessment (LCA) for unconventional sustainable building insulation materials. They concluded that there are still issues that need to be solved before a widespread use of these unconventional materials. One of their recommendations is to further investigate some properties such as durability fire resistance, water vapor diffusion, fungal resistance in particular for the best performing materials. These properties are already accounted for commercial insulation materials and in order to compete with them, newer sustainable materials must also confirm to these standards.

The thermal conductivity of composites is highly influenced by moisture absorption. Benmansour et al. (2014) had observed a rapid increase of thermal conductivity with water absorption on their natural mortar reinforced with date palm fibers for building

insulation. Alam, Singh and Limbachiya (2011) who studied the possible improvements of Vacuum Insulation Panels (VIPs) have highlighted the need of identifying newer adhesive materials, with low thermal conductivity and are chemically and physically stable under vacuum conditions and least outgas. The authors mentioned that among various components in the surrounding air, water vapour has the highest transmission rate and it permeates about 30,000 times faster than oxygen and nitrogen. Therefore, moisture is regarded as the major contributor to increasing pressure along with oxygen and nitrogen. Due to this, a better and newer class of super hydrophobic sealants and sealing processes needs to be developed to overcome the problem of permeation of moisture through the seal areas.

A comparative study was performed by Latif, Ciupala and Wijeyesekera (2014) on the hygrothermal performance of hemp and stone wool insulations in vapour open timber frame wall panels. Both composite samples showed identical thermal conductivity in identical hygrothermal boundary conditions. The U values for both samples had no significant different. However, both hemp and stone wool insulations were susceptible to mould spore germination, with stone wool facing higher risk of exposure. Similarly, the risk of interstitial condensation for stone wool insulation was also higher than hemp samples as shown by the frequency of the stone wool samples reaching 10% relative humidity. This implies the likelihood of frequent condensation in the Stone Wool-OSB interface. In comparison, the frequency and likelihood of occurrence of condensation seemed to be lower in Hemp-OSB interface. From this study, it can be observed that different filler materials provide different level of moisture exposure on the insulation materials.

Chapter 3 Methodology

3.1 Introduction

Gypsum is a commonly used building material and is especially used for interior walls. In this project, two different types of fibres, namely glass and sisal fibres are incorporated in gypsum. The effects that these fibres have on the thermal conductivity and compressive strength of gypsum are studied to evaluate the possibility of using these fibres in order to improve the performance of gypsum as a building material. This chapter describes in detail the methodology used to achieve the objectives of this study. It covers material selection, alkali treatment of fibre, observation of fibre surface, fabrication of composite samples, thermal conductivity test and compression test. The flow of the experimental programme is summarised in Figure 3.1.

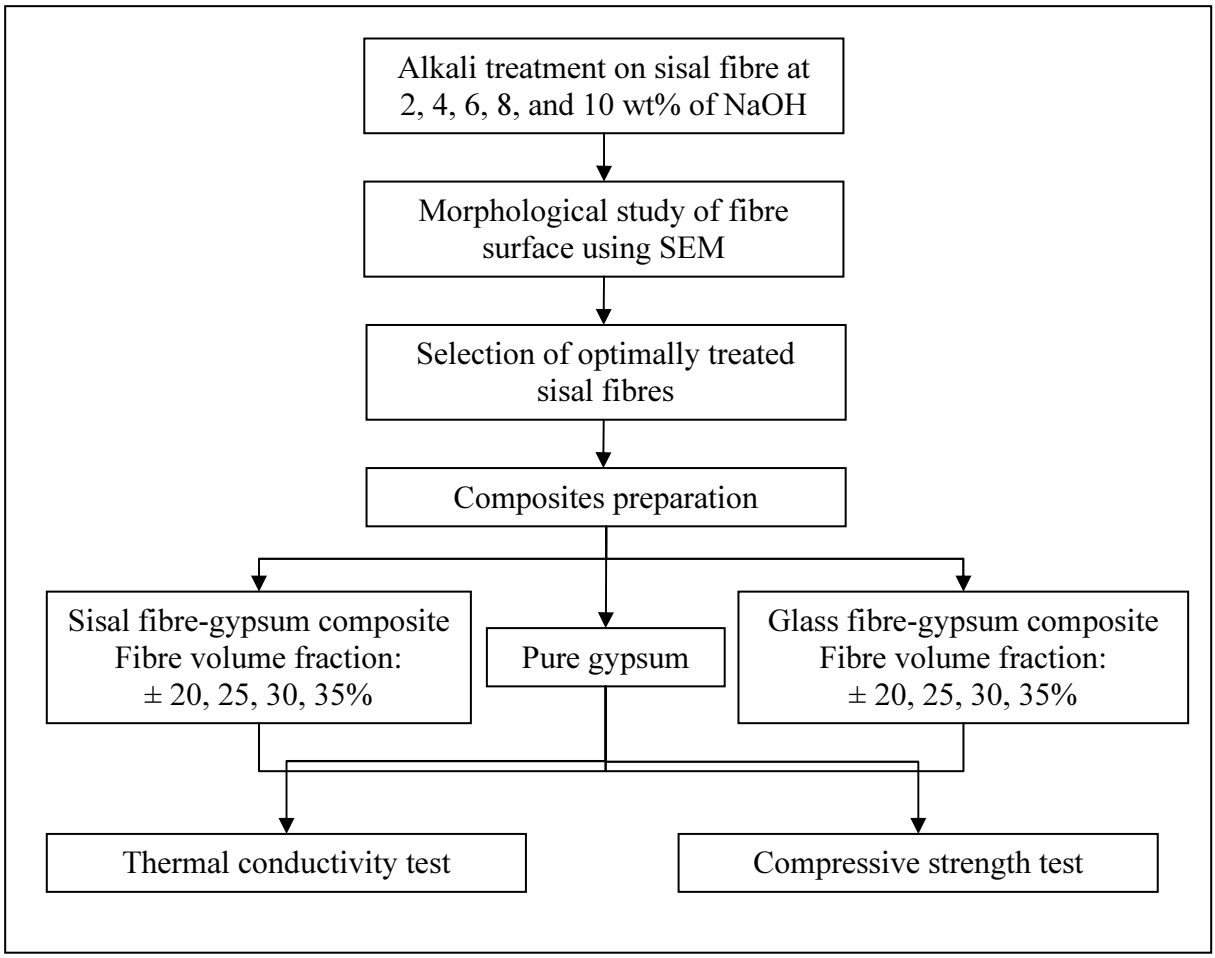


Figure 3.1: Flowchart of research scope

3.2 Materials selection

The samples used in this study comprise of pure gypsum, sisal fibres gypsum composites and glass fibres gypsum composites. Therefore, the main materials required are presented in Figure 3.2.

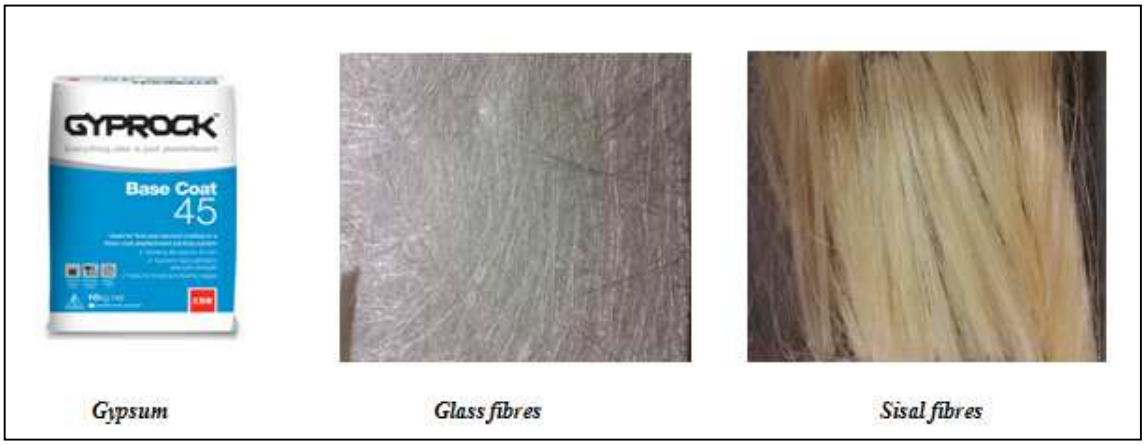


Figure 3.2: Material selection

The gypsum used in this project is in a dry powder form manufactured by Gyprock Australia and was supplied by Bunnings Warehouse. The product is Gyprock Base Coat (45) which was packed in a 10 kg bag and comprises of calcium sulphate, calcium carbonate, mica, talk and calcium carbonate.

The glass fibres used were manufactured by Diggers and was obtained from Bunnings Warehouse. The product comes as a 1.0 meter square chopped sheet fibreglass matting, with a chemical constituent of oxides of silicon, aluminium, calcium, boron and magnesium fused in an amorphous state. And as for the raw sisal fibres, they were imported from Kuwait, but are originally from West Kenya. The length of the sisal fibres were 80 cm and the diameters range from 100~250 μm. The material safety datasheet (MSDS) for the gypsum and glass fibres are attached in Appendix E.

3.2 Alkali treatment of sisal fibres

The raw sisal fibres were washed with tap water thoroughly to remove debris and dirt and then left to dry at room temperature for 24 hours. To ensure that the fibres were completely dry, they are placed in oven at temperature of 60 degree for 90 minutes. Then the cleaned fibres were cut into an average length of 100 mm. After that, the sisal fibres were divided evenly into six boxes with different sodium Hydroxide (NaOH) concentrations, i.e. 2, 4, 6, 8 and 10 wt% as shown in Figure 3.3. The NaOH liquid was produced by dissolving NaOH pallets manufactured by Scharlau at different weight percentages. The treated fibres were soaked for 24 hours at room temperature. The untreated fibres were labelled as 0% NaOH concentration. Finally, the fibres were washed again with tap water and dried in the same method prior to treatment.

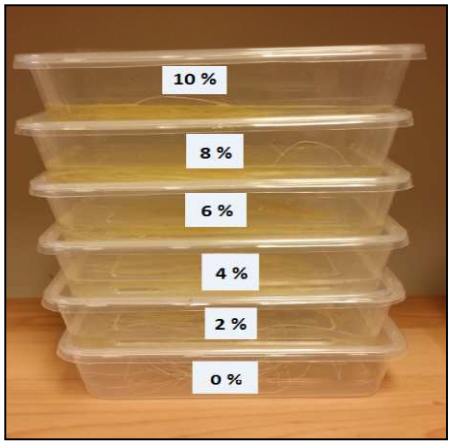


Figure 3.3: Alkalization of sisal fibres

3.3 Morphology study of fibres

Scanning Electronic Microscope (SEM) was used to investigate the morphology of sisal fibres. The SEM machine used was Jeol JCM-6000 with a balance scale range of ± 0.1 μg. A carbon adhesive disc was used to attach the fibres which were later placed on aluminium mounts. The fibres were coated with gold before placing them

in the SEM machine. Finally, the surface topography of the treated and untreated fibres was observed and the micrographs were obtained. This process is depicted in Figure 3.4.

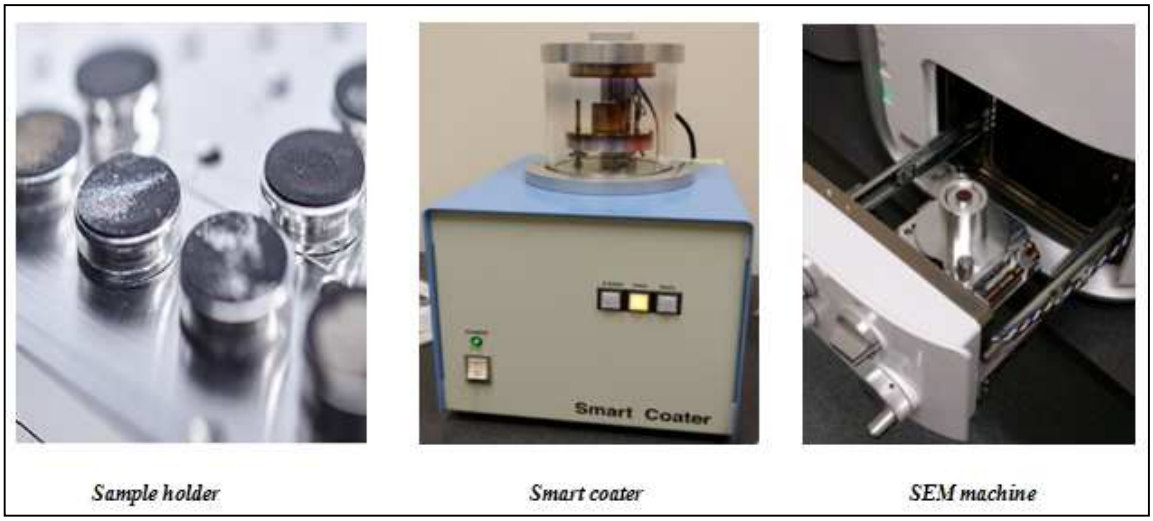


Figure 3.4: SEM examination process

3.4 Fabrication of composite samples

The composites based on Gyprock Base Coat 45 with sisal fibre (SF) and glass fibre (GF) were fabricated with variable fibre compositions (± 20, 25, 30 and 35 vol %). The composites were moulded in cylinder pipes made from PVC as shown in Figure 3.5. The dimensions of the PVC pipes were 100 cm in length and 4.5 cm in diameter. Prior to fabrication works, the interior surfaces of the PVC moulds were applied with Nu-Ceara Wax, a mould release manufactured by Huntsman Composites. The MSDS is presented in Appendix E.

Figure 3.5: PVC moulds

As per manufacturer's guidelines, the gypsum was mixed with water to form a viscous substance. With the PVC cylinders placed on a hard non-absorbent surface, these cylinders were filled with the gypsum mixed with sisal and glass fibres at various percentage of fibre volume fractions (20, 25, 30, and 35 vol %). The fibres were weighed prior to volume measurement, using 0.01 mg precision weighing scale (Sartorius CP225D). To ensure that the mixture is compacted well to produce composites with low air voids, tamping was performed on the fresh mixture at three layers using a small metal rod. For each layer, the mixture was tamped for 20 minutes.

The PVC cylinders filled with the composite mixtures were left to harden at room temperature for 24 hours. These hardened samples were then placed in an oven at 70^{o}C for 72 hours to ensure that they are completely dried. Finally, the PVC mould was cut open to release the cylindrical samples. These samples will be used for thermal conductivity test and compressive test. The samples used in this study are listed in Table 3.1.

Table 3.1: List of composite samples

Sample	Type of Fibre	Fibre Volume Fraction
PG	None	0%
SF20-G	Sisal	20%
SF25-G	Sisal	25%
SF30-G	Sisal	30%
SF35-G	Sisal	35%
GF20-G	Glass	20%
GF25-G	Glass	25%
GF30-G	Glass	30%
GF35-G	Glass	35%

3.5 Thermal conductivity test

To test the thermal conductivity of gypsum with different content of sisal fibres and glass fibres, a test setup was developed as shown in Figure 3.6. This setup consists of a heat source placed on one side of the cylindrical samples. The heat flux is expected to pass through the composites towards the other end of the samples. Prior to testing, the samples were placed inside a pipe made of PVC covered completely with an isolator made up of m-flex pipe insulation as shown in Figure 3.7. Four thermocouples were inserted in the samples at every 2 cm with another two of these thermocouples attached at both ends of the composite samples. The temperatures of the composites were measured using these thermocouples at every 5 minute intervals for a total duration of 90 minutes. The temperature measurement is based on ASTM C518. The heat gun used in this experiment is Makita thermocouple heat gun model hg 1100 cs/662q. The heat gun is set at 120^{o}C throughout the experiment.

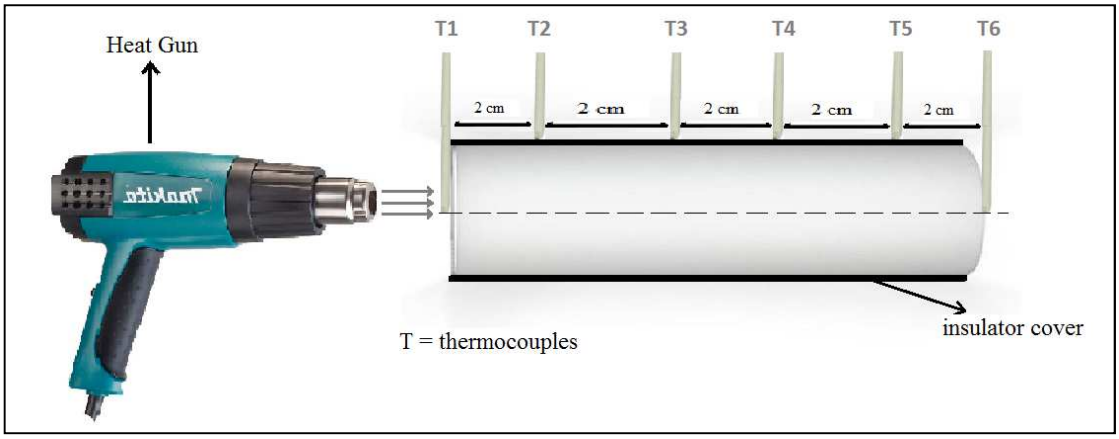


Figure 3.6: Thermal conductivity measurement

Figure 3.7: M-flex pipe insulation

3.6 Compressive test

The study of the compressive behaviour of the developed materials was performed using MTS 647 Hydraulic Wedge Grip with a 100 kN maximum capacity and at a rate of 3 mm/min. The testing machine is shown in Figure 3.8. Four samples of sisal fibre-gypsum composites, four samples of glass fibre-gypsum composites and one pure gypsum (0% fibre) were tested. The length of all the samples is 6 cm with a diameter of 4.5 cm. The software used to record the data for this test was MTS FlexTest 40. From the data obtained, the stress-strain curves were plotted and the mechanical properties of the samples were evaluated.

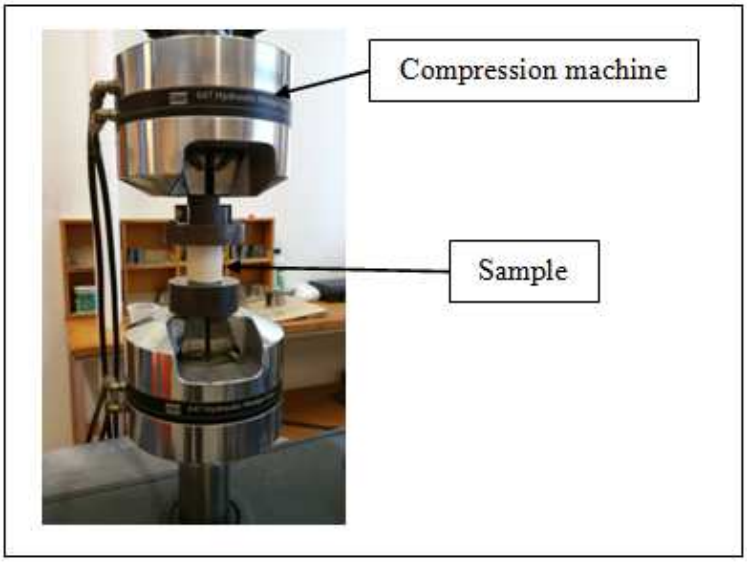


Figure 3.8: Compression testing test setup

Chapter 4 Results and Discussion

4.1 Introduction

In this chapter, the experimental results and observations made throughout the research program is presented and discussed. This includes the study on the sisal fibres and the effect of alkali treatment on its surface topography, the compressive test on the gypsum composite samples and finally, the thermal conductivity test on these samples.

4.2 Alkali treatment on sisal fibres

To better understand the role of the sisal fibres in the gypsum-fibre composites, a preliminary study is conducted on the sisal fibre itself. Its water absorptivity and diameter was measured and reported. Additionally, the effect of alkali treatment using NaOH on the surface of the fibres was also observed using SEM. A concentration of NaOH was chosen based on this observation, supported by literatures with similar testing procedure. The gypsum composites that will be used for further testings were fabricated using this optimally treated sisal fibres.

4.2.1 Preliminary study on sisal fibres

In order to study the moisture absorptivity of the sisal fibres, the dry weight of the fibres and the 24-hour soaked fibres were measured. Its moisture absorptivity was calculated using equation 4.1.

$$\text{Moisture absorption } (\%) = \frac{W_f - W_o}{W_o} \times 100 \qquad \text{Equation 4.1}$$

Where W_o and W_f denote the initial weight and the final weight of the sample, respectively.

From the measurement, it was calculated that the moisture absorption of the sisal fibres used in this test is 130%. This is comparable with what has been reported by Sen and Reddy (2011), stating a 110% of water absorption by sisal fibres. Since this indicates that the sisal fibres used are easily penetrated by water, it was ensured that the fibres were perfectly dry during composite fabrication to avoid moisture entrapment within the gypsum composite samples.

The diameter of the sisal fibres were measured using SEM and the micrograph is presented in Figure 4.1. The diameter ranges from 100~250 μm. Ratna Prasad and Mohana Rao (2011) reported that the diameter of the sisal fibres used in their study ranges from 80~300 μm with a density of 1.45 g/cm^3. The properties of the sisal fibres used in this research are summarised in Table 4.1.

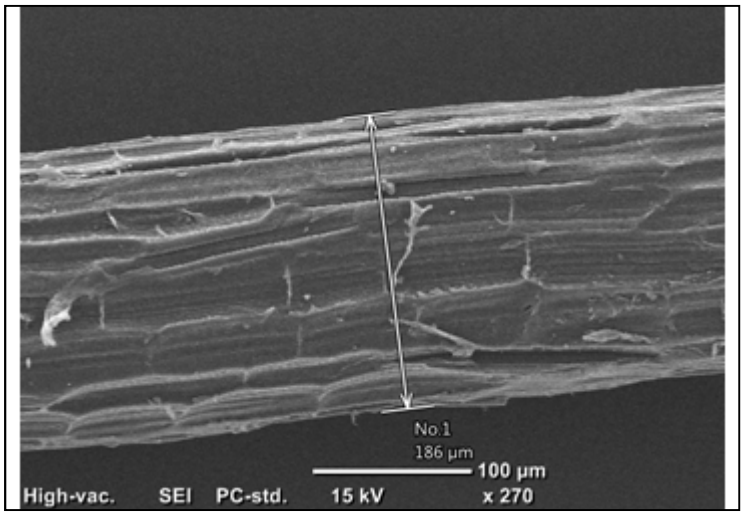


Figure 4.1: Diameter of sisal fibre

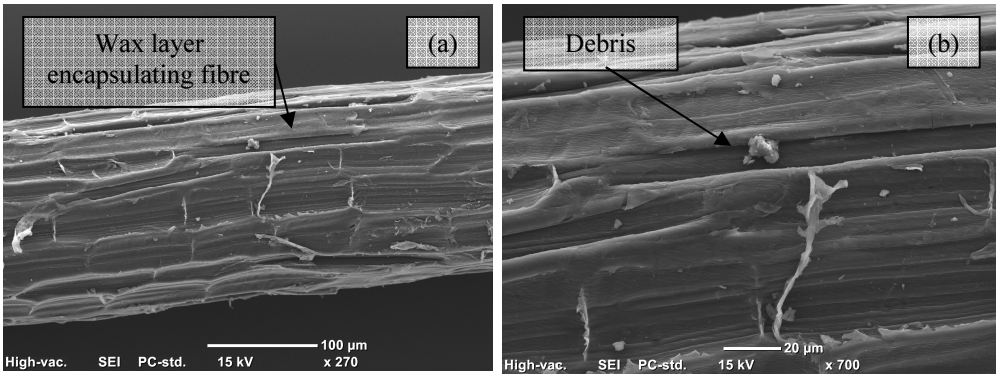
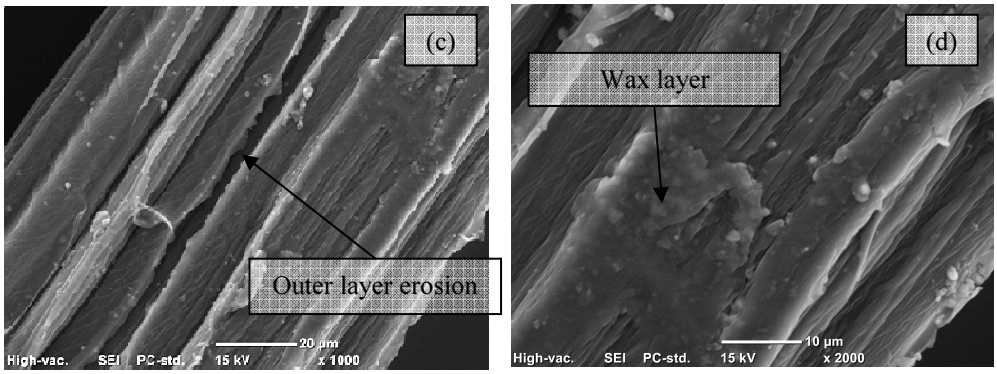
Table 4.1: Physical properties of sisal fibres

Property	
Moisture Absorption	130%
Diameter	100~250 μm

4.2.2 Morphological observation of alkali treated fibres

Before the composite samples are fabricated, the optimum percentage of NaOH treatment on the sisal fibres needs to be confirmed. Some literatures recommended a concentration of NaOH between 4 to 8 %; however, each natural fibre may have different response to the NaOH. Therefore, the NaOH percentage effect on the sisal fibre imported from Kuwait needs to be investigated to ensure the best interfacial adhesion with the gypsum matrix.

The sisal fibres were treated with NaOH at 2, 4, 6, 8, and 10 wt%. The changes in the surface morphology of the fibres were observed using SEM to determine the effect of the alkali concentration on the sisal fibres. The micrographs are presented in Figure 4.2.

NaOH Concentration	SEM
0%	
2%	

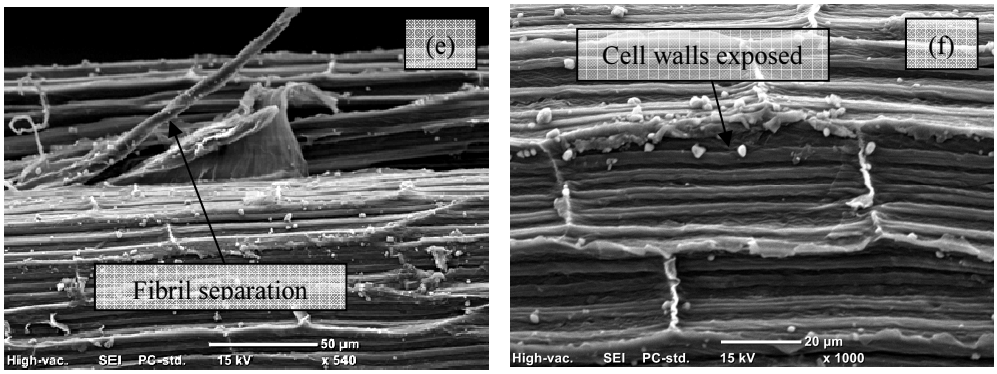
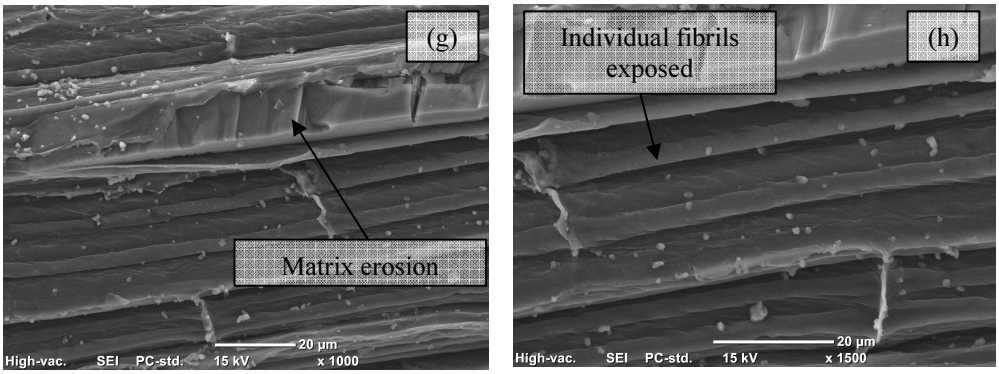
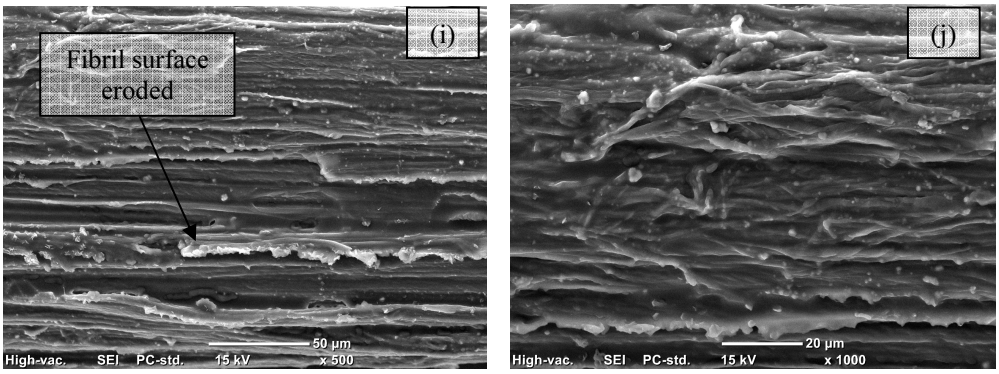
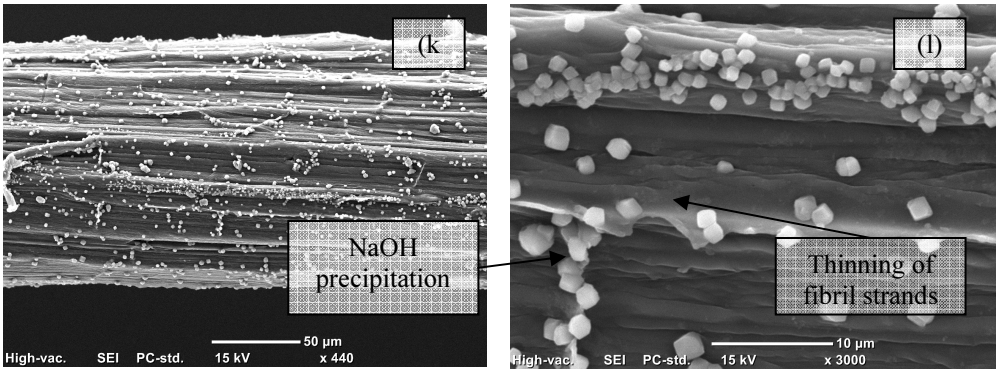
4%	
6%	
8%	
10%	

Figure 4.2: Morphology of sisal fibres at different concentration of NaOH treatment

From Figure 4.2, it can be seen that sisal fibre without treatment (0% NaOH) is covered by a smooth waxy layer and some impurities. This layer may reduce the interfacial adhesion between the fibre and the gypsum. However, with increment of the NaOH concentration to 2%, it is observed that some of the waxy layer has been eroded. The surface can be seen rougher than the untreated fibres. At 4% NaOH concentration, the waxy layer is absent, revealing the cell walls of the fibre. Some fibril separation can also be observed. Cleaner fibre surface was observed at 6% NaOH concentration. Individual fibrils surface can be clearly seen with some fibre matrix erosion. The exposure of these fibrils provides uneven surface topography of the fibres which will be favourable for better interlocking with the gypsum. At higher NaOH concentration of 8%, it can be observed that the surface of the fibre looks relatively eroded. This indicates that the fibres are starting to damage. As a consequence, at a very high concentration of 10% NaOH, it is expected that more damage will occur on the surface of the sisal fibre. At higher magnification, it was observed that the individual fibrils are thinning due to the erosion by the corrosive NaOH. This will evidently weaken the fibre strength. Additionally, NaOH precipitation is observed on the fibre surface. The high concentration of NaOH requires longer rinsing with water in order to remove these precipitations.

Therefore, from these observations, it can be concluded that 6% NaOH concentration is ideal for the treatment of sisal fibres. To strengthen this selection, reference has been made on other literatures. An intensive study has been conducted by Azwa (2014) on bamboo fibres. NaOH treatment at 6% concentration has shown to be the optimal concentration, resulting in the highest tensile properties for the single bamboo fibres. The author had similar SEM results as discussed in this study. The bamboo fibres had apparent damages on its fibrils. Similar studies using proximate concentration of 5% NaOH revealed comparable outcomes. A research by Elenga et al. (2013) on raffia fibres showed that 5% NaOH treatment resulted in the highest increase in tensile strength, about 129%, while the elongation at failure was about 175%. These properties decreased at higher NaOH concentrations. Similar results were achieved on Borassus fruit fibre, whereby highest increment of tensile strength was observed on 5% NaOH treated fibres which decreased at higher concentrations

(Obi Reddy et al. 2013). The adhesion of bamboo fibres to unsaturated polyester matrix were studied by Wong, Yousif and Low (2010). Both Wong, Yousif and Low (2010) and Azwa (2014) found that at 5% and 6% NaOH concentration, respectively, had the best adhesive strength with the matrix. In conclusion, the gypsum composites will be fabricated using sisal fibres treated at 6% NaOH to perform further testings.

4.3 Compressive behaviour of composite samples

In this section, the results of the compression test on the samples i.e. pure gypsum, sisal fibre-gypsum composites and glass fibre-gypsum composites are discussed. The effect of different volume fraction on the compression strength of the composites is evaluated. The comparison between the two fibre reinforcement on the composite strength is also reported.

4.3.1 Sisal fibre-gypsum composites

Figure 4.3 shows the stress strain diagram for different composites based on sisal with different volume fractions. The trends of the stress seem to show elastic and plastic deformation for all the composites. Most of the composites exhibit similar strain values. In other words they have similar ductility. However, pure gypsum shows brittle nature, since the strain value is much lesser than the composites. In term of strength, all the sisal composites shows higher strength compared to the pure gypsum sample. In other words, the addition of the sisal significantly improves the compressive strength of the gypsum from strength and ductility point of views. This has been reviewed by John and Thomas (2008) on various natural fire based composites whereby the addition of fibres reinforced the mechanical strength of the matrix material. The increase in volume fraction of fibres up to a certain level was also observed by Anbukarasi and Kalaiselvam (2015) to produce higher compressive strength on luffa reinforced epoxy composites.

With respect to the influence of the fibre volume fractions on the strength of the composites, it seems that the 25 and 20 vol. % of the sisal fibres introduced the highest strength to the composites compared to the highest volume fraction of 35 %. In other words, there is an optimum volume fraction that needs to be considered to obtain the highest composite strength. There are various reasons which can contribute to these results. When the fibre contents increase in the composites, there is no sufficient matrix to support the fibres and ensure the integrity of the composites. This has been reported by many researches. Anbukarasi and Kalaiselvam (2015) observed that air entrapment in the composites due to fibre agglomeration and non-homogeneous filling of particles and short fibres reduced the stress transfer between the fibres and the matrix. The same effect was also reported by Shalwan and Yousif (2014) whereby high content of the graphite fillers deteriorates the mechanical properties of natural fibre epoxy composites.

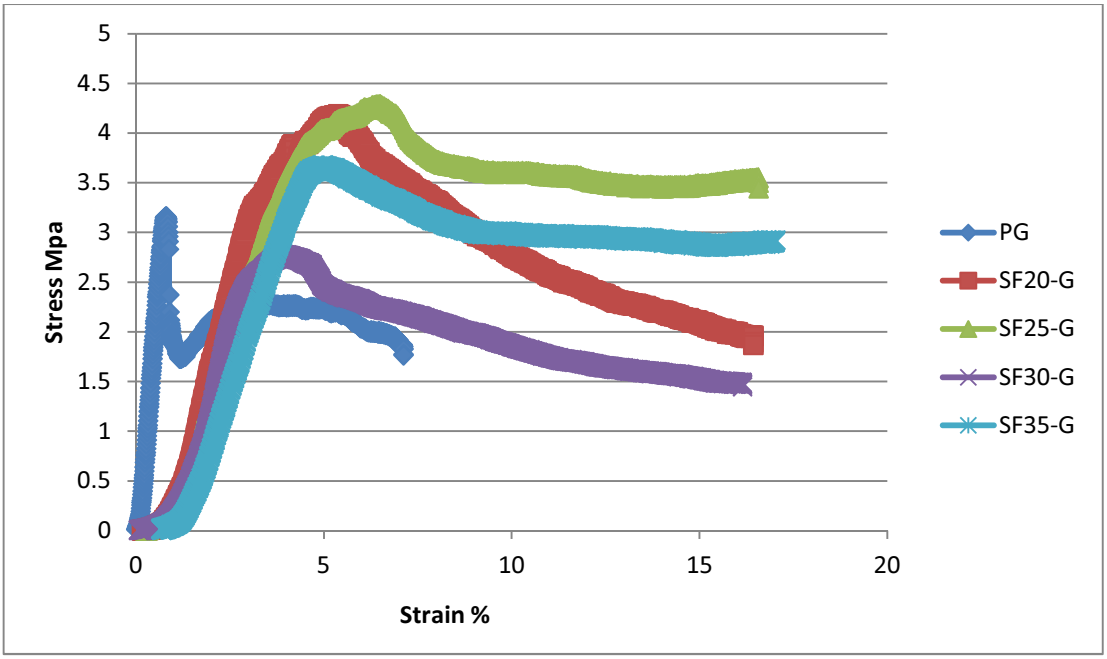


Figure 4.3: Stress-strain diagrams of sisal fibre-gypsum composites

4.3.2 Glass fibre-gypsum composites

Similarly to the sisal fibre-gypsum composites, Figure 4.4 shows the stress-strain diagram for different composites reinforced with glass fibres at different volume fractions. As shown on the diagram, it seems that the effect of fibre volume fraction is more pronounced for glass fibres. The increment in strength is observed for GF25-G and GF30-G, but decreased tremendously for GF35-G. This indicates that the higher content of glass fibres leads to insufficient matrices to provide cohesion within the composite. Therefore, the optimum volume fraction for glass fibre in gypsum composite shall be 30 vol.%.

The effect of adding glass fibres and reinforcement in concrete was observed by Patil and Kulkarni (2014). The compressive strength reached a maximum at 0.5% fibre content and started to decrease at higher content. This outcome is similar to what has been observed in this study. The compressive behaviour of glass/epoxy composite was studied by Liebig et al. (2015), focusing on the effect of voids on the strength reduction. It was reported that the compressive failure is initiated significantly by the stiffness of matrix and fibres, the fibre foundation and the fibre misalignment. Additionally, the aspect ratio of voids in the matrix results in stress concentration that leads to premature fibre-matrix debonding and to a continuous loss in stability of the fibre. Therefore, in relation to the high glass fibre volume fraction in the composite samples, it can be concurred that the higher volume of voids trapped between the stiff fibres may have acted as weak points for initiation of failure. The strain values for the GF-G composite samples differ with fibre volume fraction. However, in comparison to pure gypsum, they are more ductile.

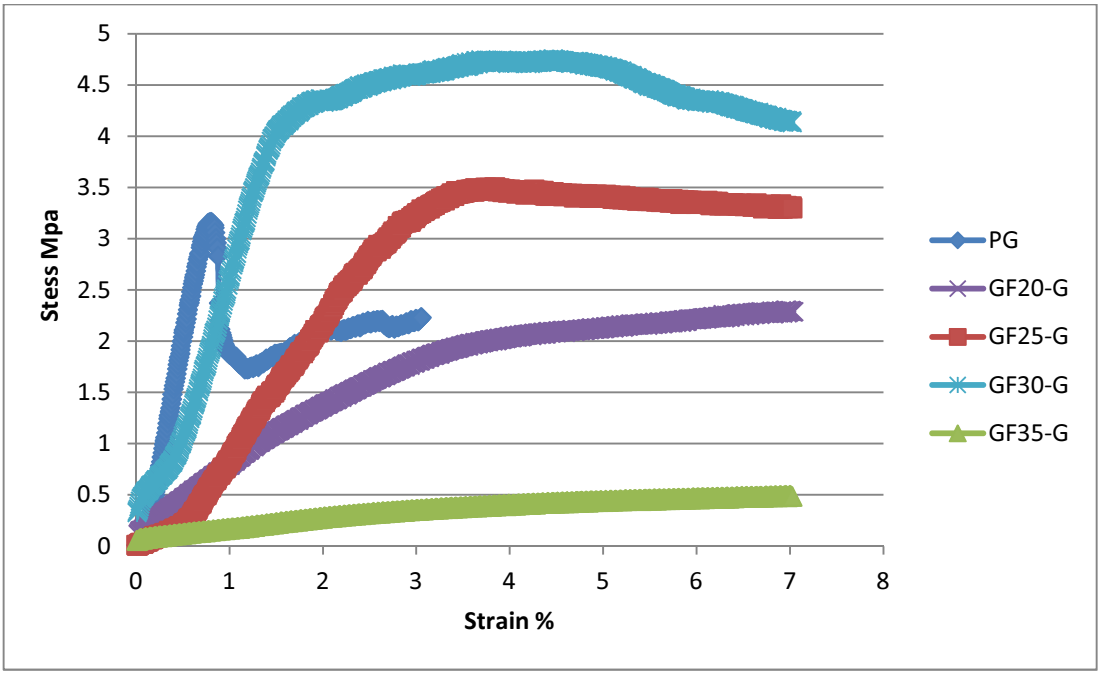


Figure 4.4: Stress-strain diagrams of glass fibre-gypsum composites

4.3.3 Comparison between sisal and glass fibre-gypsum composites

The strengths of both composites with different fibre materials were compared and are presented in Figure 4.5. The highest compression strength achieved in both cases was at ±4.75 MPa by GF30-G, the composite sample with 30 vol.% glass fibres. However, for the other fibre volume fractions, sisal fibre-gypsum composites have higher strength than glass fibre-gypsum composites for the same fibre content.

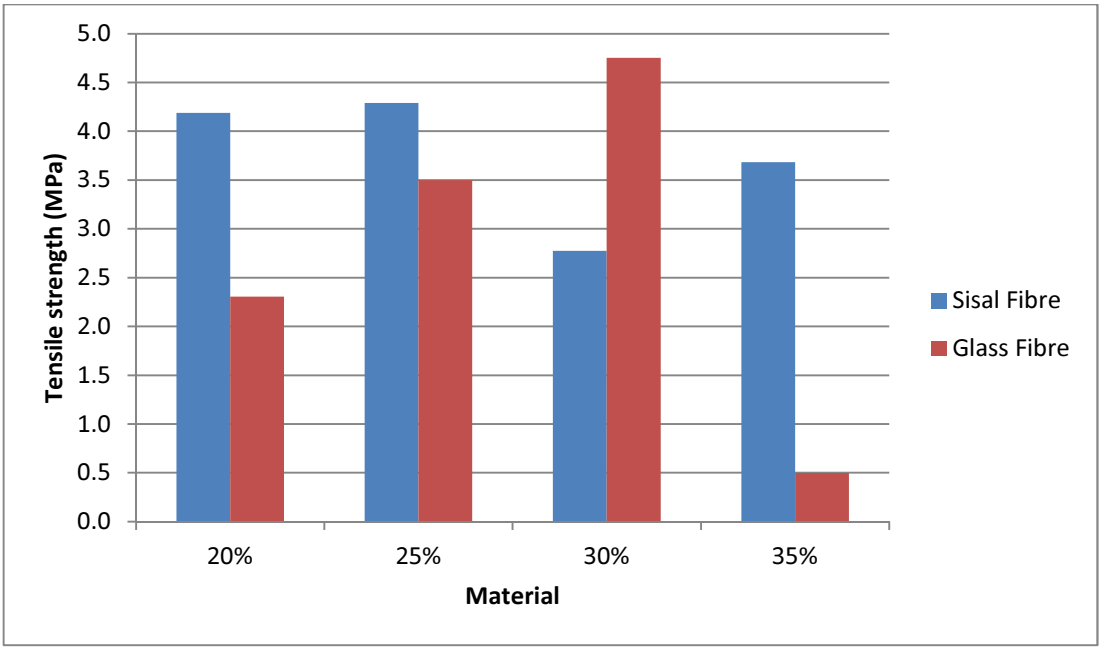
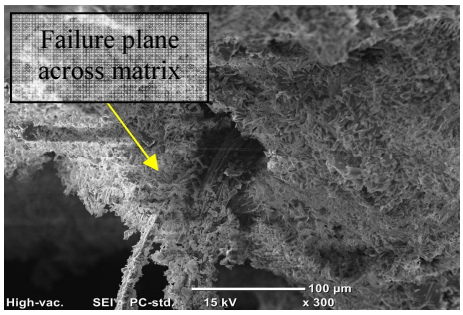
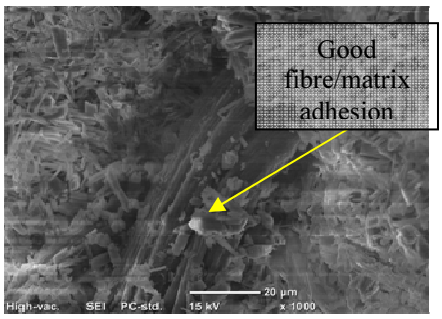
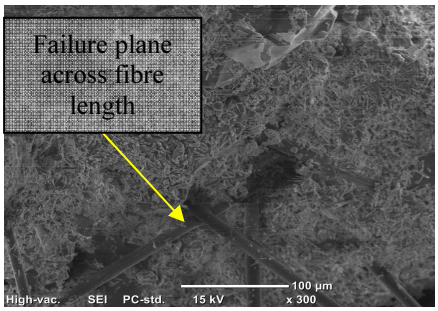
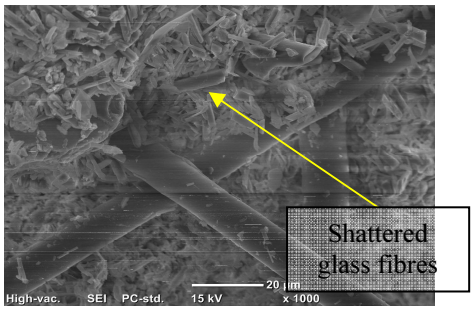
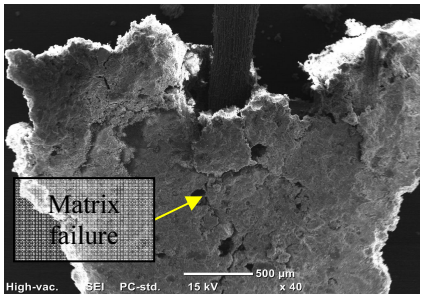
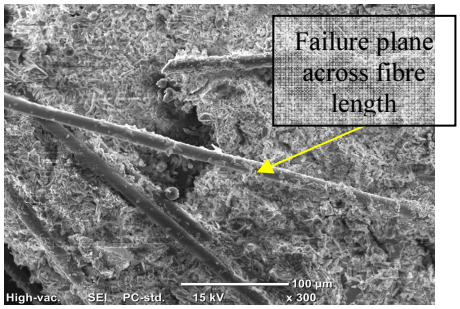


Figure 4.5: Tensile strength of sisal and glass fibre-gypsum composites

It was reported by Baets et al. (2015) that natural fibre composites performs less in compression compared to glass fibre composites. However, other researchers have reported that natural fibres perform comparably well in compression as glass fibres, and in some cases, slightly better. Gupta (2009) has obtained a value of 32 MPa on the compressive strength of flax fibre-epoxy composite which was comparable to 31.2 MPa for glass fibre-epoxy composite. For sisal fibre composite laminates, Samuel, Agbo and Adekanye (2012) have obtained a compressive strength of 42 MPa, higher than the E-glass composite laminate strength of 37.75 MPa. They showed that natural fibre composites are at par with glass fibre composites in terms of their compressive strength but performs very poorly in tensile. Therefore, apart from GF30-G, generally, it was observed that the sisal fibre-gypsum composites are better in compression than the glass fibre-gypsum composites. This indicates that the sisal fibre-gypsum composite is a suitable candidate for wall panelling material in buildings.

4.3.3 Morphology of fractured samples

The samples fractured through the compression test were retrieved for morphological observation using SEM. The micrographs of the composites are presented in Figure 4.6.

Fibre Volume Fraction	Sisal Fibre-Gypsum Composites	Glass Fibre-Gypsum Composites
20%	 	 
25%		

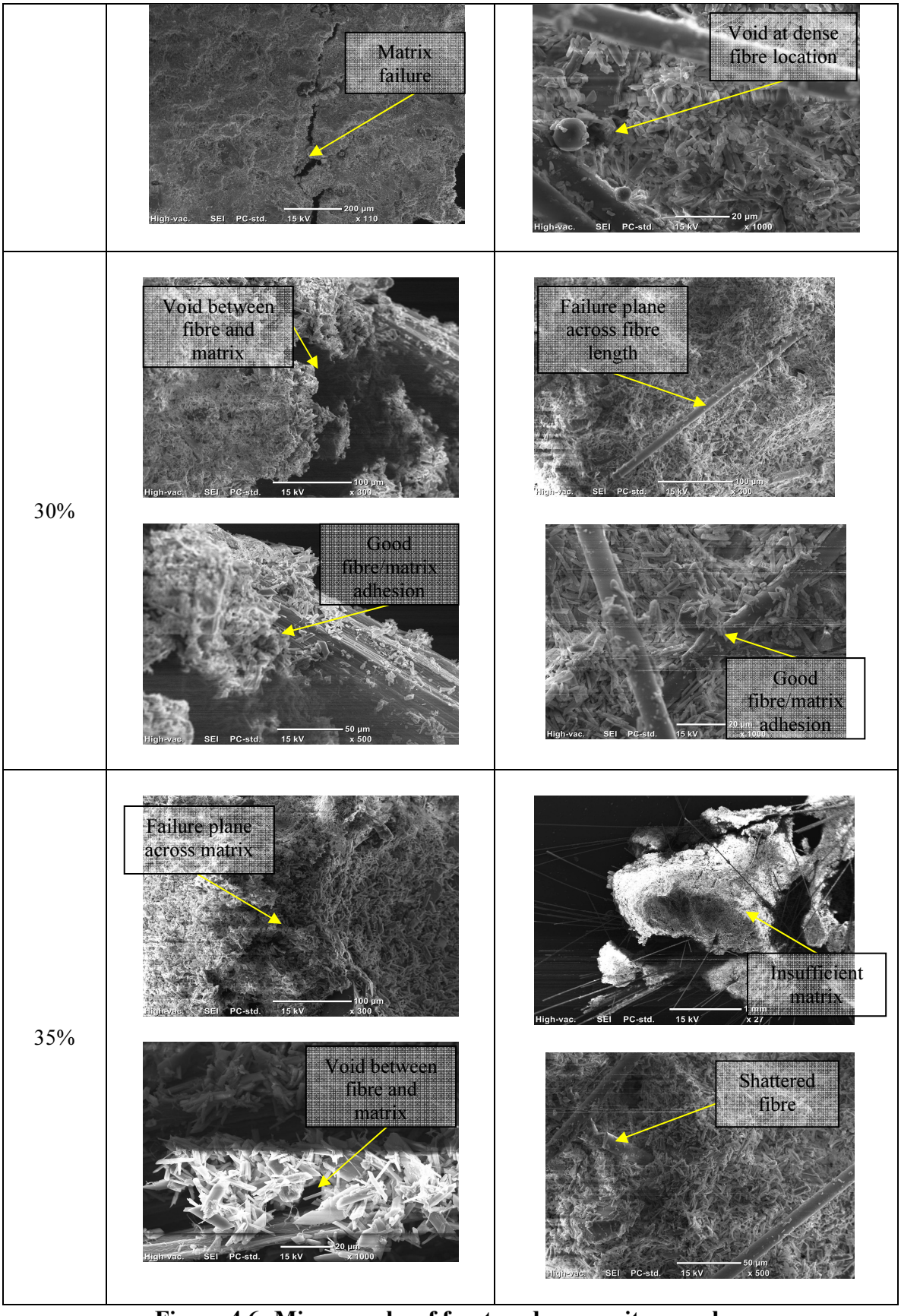


Figure 4.6: Micrographs of fractured composite samples

Firstly, from the micrographs of the sisal fibre-gypsum composites, it is apparent that the gypsum particles are firmly attached on the sisal fibres. This is shown for 20% and 30% fibre volume fraction of sisal fibres. The rough fibre surface provides a good medium for interlocking with the gypsum matrix. Therefore, through SEM observations, we can prove that the sisal fibres treated with 6% NaOH concentration results in good fibre-matrix adhesion. The study of the fibre-matrix interface of natural fibres is commonly accompanied by SEM observations. Annie Paul et al. (2008) have made a comparison between untreated and treated banana fibres on the adhesion with polypropylene resin. The fibres were treated with NaOH and benzoyl chloride. SEM observations were performed on the failed composites after tensile loading. The untreated samples showed holes within the matrix caused by debonding of fibres. This indicates weak adhesion between the fibre and the matrix. Significant improvement in the fibre/matrix adhesion was reported by the absence of holes and debonding of the fibres. The fracture surfaces of the treated fibre composites instead, show fibre breakage rather than pullout. This is caused by higher interfacial strength. The same phenomenon was reported by Shanmugam and Thiruchitrambalam (2013) on Palmyra Palm Leaf Stalk fibre, hybridized with jute fibres as reinforcement for polyester resin. Less fibre pullouts were observed through SEM for treated fibres as compared to the untreated fibres. The author suggested that the alkali treatment had reduced the possibility of debonding of the fibre-matrix interface thus increasing the strength of the composites. It was mentioned by Rout et al. (2001) that through their SEM study, existence of cracks at the broken fibre ends/ sites in 5% alkali treated coir-polyester composite suggested that the failure occurred at the fibre due to strong adhesion between the fibre and matrix. The holes found in the fractured coir-polyester composites without fibre treatment showed incompatibility of untreated fibre surface with the polyester matrix. The holes were left after the fibres are pulled out from the matrix when tensile stress is applied. In this study, such holes could not be observed due to nature of the load applied. As the gypsum composites in this study were compressed, fibre pullout was not possible as the direction of loading was in the opposite direction as compared to the ones reported by these literatures. Therefore, a different mode of failure is expected for the gypsum composites.

In comparison between the failure modes of the two types of composites, it is clear that the compressive load have resulted in different mechanism of failure. For the sisal fibre-gypsum composites, the fracture plane was observed to occur across the gypsum matrix. At 20% volume fraction, the micrograph shows a fracture plane across the end of a sisal fibre while at 25%, the side view of the composite shows obvious matrix cracking. At 35% volume fraction, the fracture plane cut across the matrix surface, with no visible fibre can be observed which may indicate that the failure occur without significant effect from the fibres. However, for the glass fibre-gypsum composites, at each volume fraction, we can see a similar pattern on the fractured surface, whereby glass fibres are visible, with the plane cutting across them longitudinally, meaning across the length of the fibres. This is evident that the failure was dominated by delamination of the composites, with the interface of the separation is along the glass fibres. The difference on the location of failure between these two composites may be attributed by the properties of the fibres. As the glass fibres are stiff and rigid compared to the sisal fibres, they are not able to deform easily as the compressive pressure are being applied. This causes the interlocking between the matrix and the fibres to weaken; resulting in slipping and breaking of the composites across the length of the fibres. Other fibres at different orientation in respect to the failure plane are broken or crushed during the failure process. This can be observed on micrographs for 20 and 35% volume fraction. The glass fibres were shattered in order to release the stress build-up within the composite samples. On the other hand, the sisal fibre is easier to deform and to adjust itself as the composites are being compressed. Therefore, the matrix cracks with less influence by the flexible fibres.

At higher volume fractions, the presence of voids is identifiable from the micrographs of both composites. For the sisal fibre-gypsum composites, voids are presence in between fibres at 30 and 35% volume fraction, while at 35% glass fibre content, the fractured sample show insufficient matrix. The increase amount of fibres may have restricted the flow of matrix to encapsulate the fibres during fabrication. This may result in reduced strength of the composites. Anbukarasi and Kalaiselvam (2015) have observed fibre agglomeration on luffa reinforced epoxy composites for

randomly oriented short fibre and particle fibre from their SEM images. The authors concluded that the non-homogeneous filling of particle and short fibre in matrices and probability for overlap increased the chances for air entrapment, which results in poor stress transfer. Liebig et al. (2015) had observed through SEM the impact of voids on a composite based on carbon fibres. They reported that the compression, tension face and the neutral axis were present for fibres close to the void. The aspect ratio of the voids causes stress concentrations in the matrix, leading to premature fibre-matrix debonding and further destabilisation of the fibre, depending on its foundation, which finally causes fibre kinking. Due to riverlines on the matrix, further fibre failure appears after the fibres close to the void were kinked out. This is illustrated in **Error! Reference source not found.**.

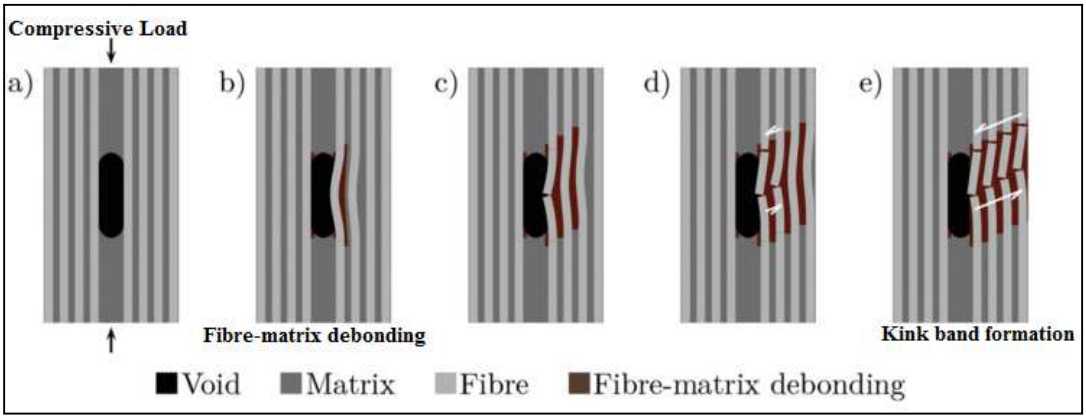


Figure 4.7: Kink-band formation near voids in fibre composites (Liebig et al. 2015)

4.4 Thermal conductivity of composite samples

In this section, the results of the heat conductivity study are presented. The test was conducted on pure gypsum, sisal fibre-gypsum composites and glass fibre-gypsum composites with prolong heat exposure of 120°C at T1. The reading for temperature increment up until 90 minutes were taken at points T1, T2, T3, T4, T5 and T6 as per Figure 4.8. The difference in the temperature between adjacent points was calculated as ΔT1, ΔT2, ΔT3, ΔT4 and ΔT5. The effect of different volume fraction on the

thermal condcutivity of the composites is evaluated. The comparison between the two fibre reinforcement on the composites' conductivity is also reported.

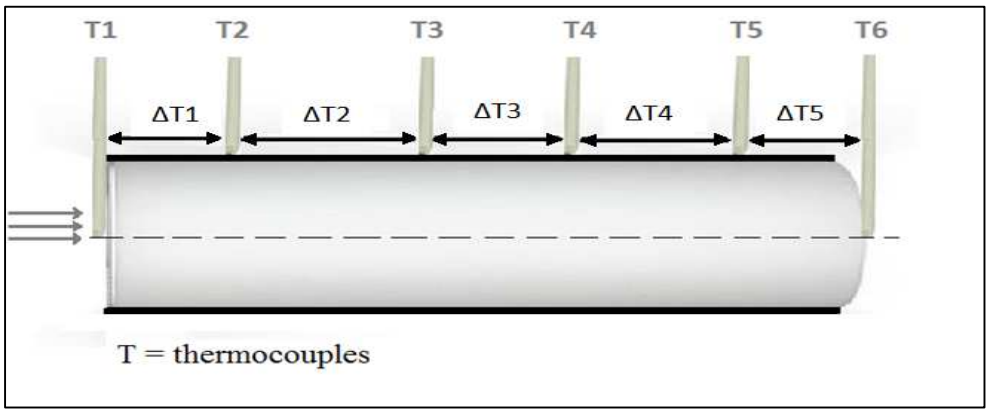


Figure 4.8: Temperature reading across samples

4.4.1 Sisal fibre-gypsum composites

The final temperature differences between adjacent points across the sisal fibre-gypsum samples are calculated and tabulated in Table 4.2.

Table 4.2: Temperatute difference across sisal fibre-gypsum composites

Materials	ΔT1	ΔT2	ΔT3	ΔT4	ΔT5
PG	62.7	15.5	12.4	4.0	0.3
SF20-G	67.4	17.5	7.1	3.3	2.3
SF25-G	68.5	15.7	6.8	3.3	0.6
SF30-G	71.0	18.8	8.9	4.6	0.6
SF35-G	73.0	15.8	7.8	3.9	2.2

From Figure 4.9, it can be observed that ΔT1 shows consistent reading for all samples. ΔT1 increases with the addition of sisal fibres, with the maximum achieved by SF35-G. The higher temperature difference between point T1 and point T2 indicates that less heat had been transferred across the two points, resulting in higher temperature gap. This shows that with the addition of sisal fibres, the heat

conductivity of the composite decreases, making it a better heat insulation. The increment in heat insulation properties is 7.50, 9.25, 13.24 and 16.43% for 20, 25, 30 and 35 vol. % of sisal fibres, respectively.

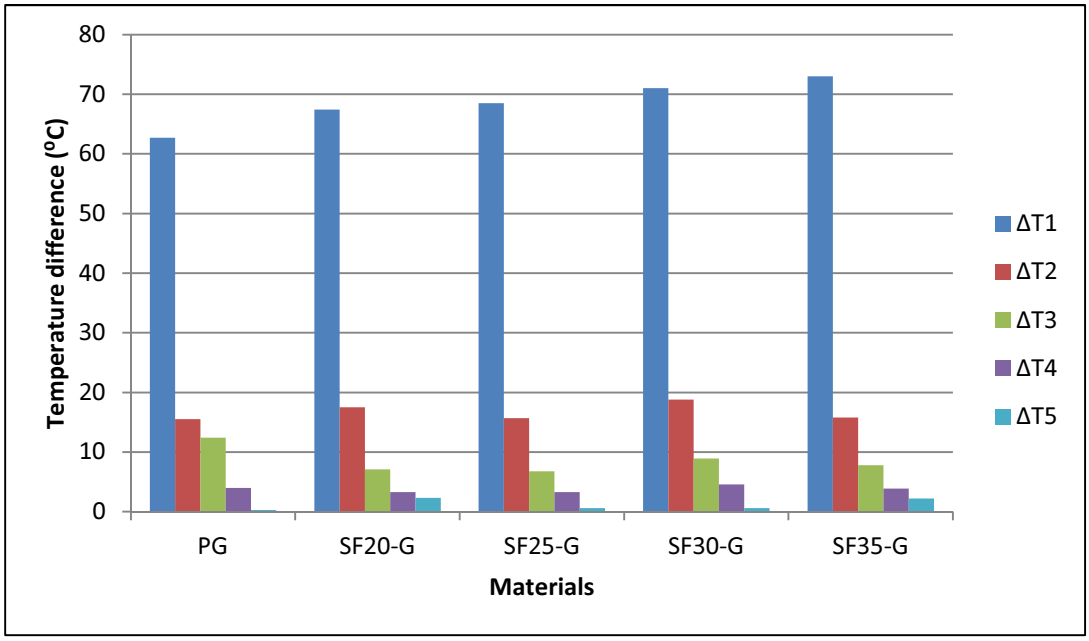


Figure 4.9: Temperature difference at 90 minutes for sisal fibre-gypsum composites

However, the data collected at ΔT2, 3, 4 and 5 do not present good correlation. This may have been caused by:

1. The distant from the heat source.

   As the location of measurement becomes further from the heat source, the effect of heat becomes less sensitive. Therefore, the accuracy of the data collected by the thermocouples may have been reduced.
2. Randomness of the particles inside the samples.

   The heat conductivity may be affected by air entrapments and the fibre distributions. It is difficult to standardise the fibre distribution within the samples as they are randomly oriented during sample fabrication. The transfer of heat may be affected by locations with high void contents or dense fibre volume which are not homogenous across each sample.

In comparison with other research works, it was highlighted by Chikhi et al. (2013) that the thermal conductivity of gypsum based materials decreases with increasing the date palm fibres concentration. The authors noted that the reduction in heat conductivity was caused by increased fibre loading, whereby the fibres are less conductive than the gypsum. Ashour et al. (2010) measured the thermal conductivity of natural plaster materials that could be used for straw bale buildings. They have found that by increasing wheat straw fibres percentages from 0% to 75%, the thermal insulation increased to 43.9%, 43.4%, and 39.8% for temperatures of 10, 25 and 40^{o}C in a comparison with plaster material without reinforcement fibres. In terms of presence of air voids in the samples, a case study was conducted by Pia and Sanna (2014) regarding the influence of microstructure voids on thermal conductivity in fractal porous media. The results proved that thermal conductivity is considerably influenced by pore size, geometric organization and complexity of the porous media. Importantly, "pore walls" and a great number of small pores found in materials decrease the value of thermal conductivity. Therefore, this supports the hypothesis of inconsistency of the results for ΔT2, 3, 4 and 5.

4.4.2 Glass fibre-gypsum composites

The final temperature differences between adjacent points across the glass fibre-gypsum samples are calculated and tabulated in

Table 4.3.

Table 4.3: Temperatute difference across glass fibre-gypsum composites

Materials	ΔT1	ΔT2	ΔT3	ΔT4	ΔT5
PG	62.7	15.5	12.4	4.0	0.3
GF20-G	63.5	17.2	9.8	4.6	1.4
GF25-G	65.6	16.4	8.1	3.3	1.2
GF30-G	67.2	16.8	7.1	3.0	0.4

GF35-G	68.2	19.7	7.8	4.7	1.2

As observed in Figure 4.10, similar results were obtained for glass fibre-gypsum composites as compared to sisal fibre-gypsum composite which was previously discussed. Steady increment for ΔT1 occurred as the volume of glass fibres is increased. Pure gypsum showed relatively high heat transfer than the samples with glass fibres. The increment in heat insulation properties is 1.28, 4.63, 7.18 and 8.77% for 20, 25, 30 and 35 vol. % of glass fibres, respectively. This again shows that the presence of fibres have slowed down the transfer of heat across the sample making gypsum less conductive to heat.

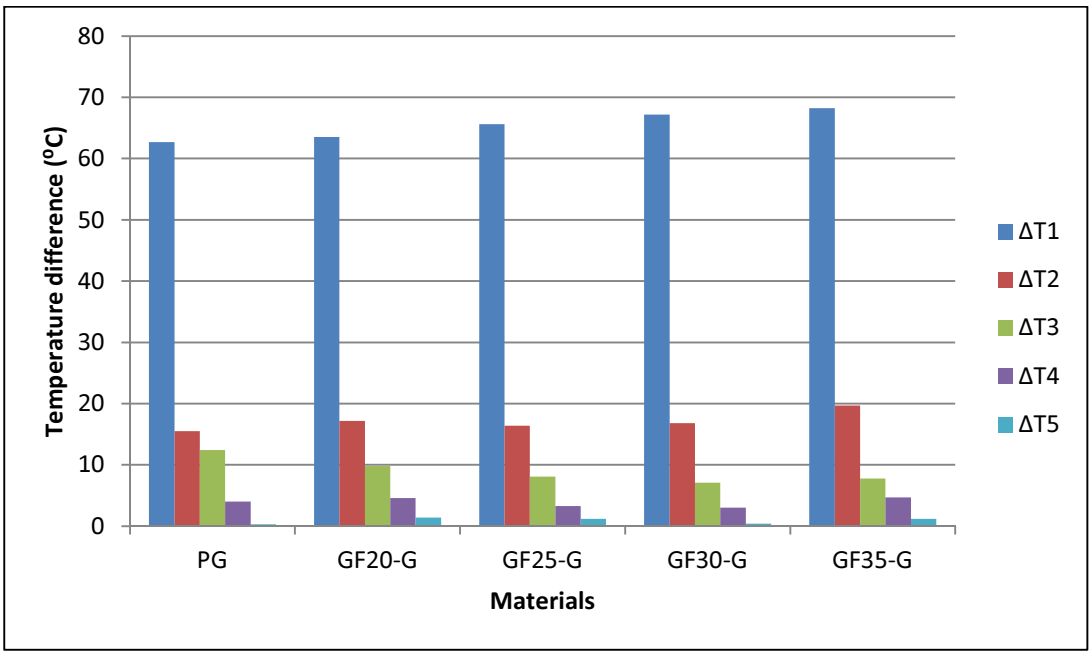


Figure 4.10: Temperature difference at 90 minutes for glass fibre-gypsum composites

Again, it was hard to find a correlation for ΔT2, 3, 4 and 5 as the data collected had insignificant differences between all the samples. The same hypothesis as previously discussed may have also contributed to this occurrence. This has been comprehensively studied by Cao et al. (2015) on the thermal insulation properties of the glass fibre board used for interior building envelope. The author agreed that it is difficult to directly describe the internal structure of a porous medium due to its

complex and stochastic nature. Only statistic-based structural information is possible to obtain and this includes porosity, fibre diameter distributions and fractal dimension. It was also highlighted that the effective thermal conductivity decreases with the increasing porosity at a near-linear rate.

4.3.3 Comparison between sisal and glass fibre-gypsum composites

The data obtained for ΔT1 at the end of the test for both sisal fibre-gypsum composites and glass-fibre gypsum composites were compared and presented in Figure 4.11.

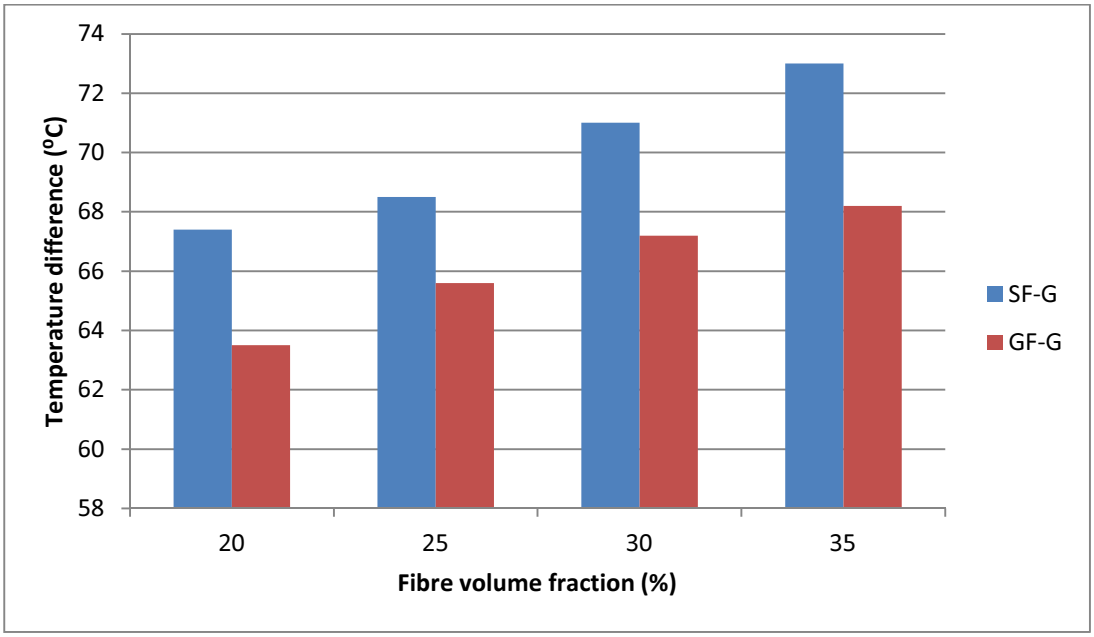


Figure 4.11: Temperature difference at 90 minutes for ΔT1 of both composite samples

For all volume fractions, the temperature differences for sisal based samples are higher than glass fibre composites by 6.14, 4.42, 5.65 and 7.04% at 20, 25, 30, and 35 vol%, respectively. Similar results were obtained by a few researchers. A study conducted by Mounika et al. (2012) have shown that the increased in volume fraction of bamboo fibre (from 0.15-0.30%) in polyester resin have decreased the thermal conductivity of the composites from 0.211 W/mK to 0.185 W/mK. This is

lower than the thermal conductivity of glass fibre-polyester composite which was measured as 2.23 W/mK. The author attributed this to the porosity of the core of the fibres where air is entrapped, as higher voids reduce thermal conduction. Another study on borassus seed shoot fibre reinforced polyester composite had also shown a decrease in thermal conductivity from 0.193 to 0.176 Wm/K as the fibre volume fraction increase from 0 to 0.31% (Narendra, Murthy & Jayananda 2014). This is also considerably lower than polyester composites with glass fibres. Similarly, Panyakaew and Fotios (2011) found that insulation board made from coconut husk and bagasse has a thermal conductivity value from 0.046 to 0.068 W/mK and are comparable to cellulose fibres and mineral wool. These authors have agreed that these bio-materials may be considered as building components to decrease heat transfer in air conditioned buildings which will assist in the reduction of energy consumption.

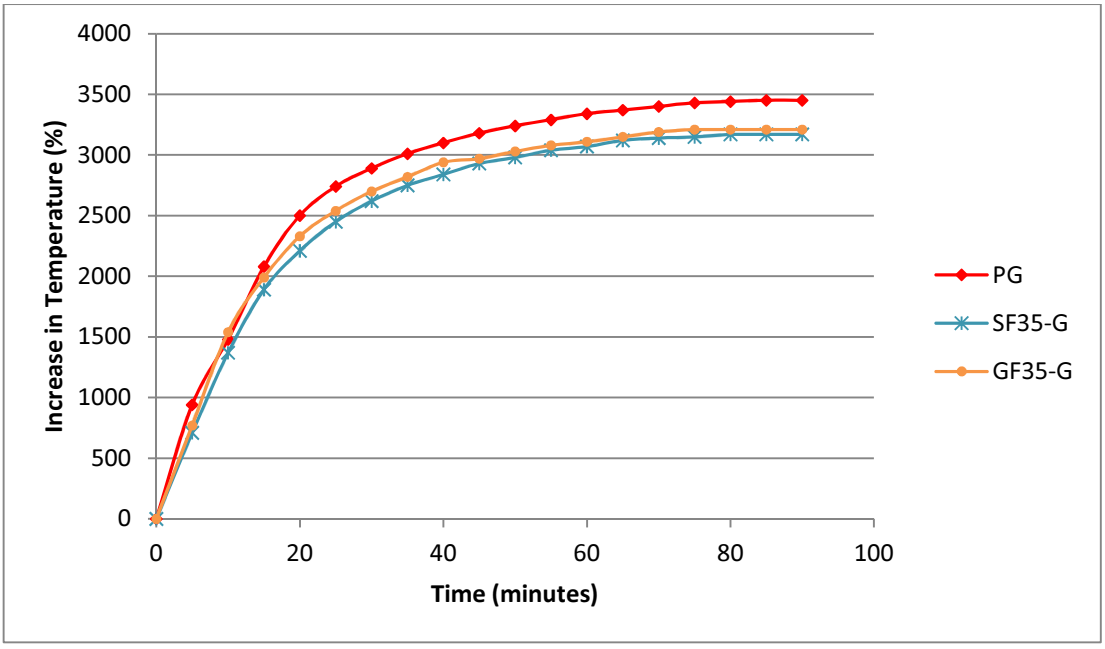


Figure 4.12: Temperature increase at T2 from 0 to 90 minutes

Figure 4.12 presents the percentage of temperature increment at T2 for pure gypsum and the composites with both fibres at 35% volume fraction. T2 experienced the most consistent increment as compared to the other thermocouples. From the figure, it can be observed that both types of fibres have effectively reduced the thermal

conductivity of gypsum, with sisal showing a slightly better result than glass throughout the test duration. Both have shown reduction in heat transfer rate at 15 minutes while the reduction in heat for pure gypsum starts at approximately 20 minutes. Individually, the thermal conductivity of the sisal fibres and glass fibres are 0.042 and 0.038 W/mK, respectively as reported by Neira and Marinho (2009). This shows that both types of fibres will have contributed similar degree of insulating property to the gypsum composite. Therefore, it can be concluded that the contribution of sisal fibres in insulating heat is comparable to glass fibres, and with proper composite fabrication, sisal fibres can be utilised to assist in reinforcing and insulating gypsum for wall panels in buildings.

Chapter 5 Conclusions and Recommendations

5.1 Conclusions

Based on the results obtained from this study, it can be concluded that:

1. The alkalization on the sisal fibres have provided different levels of treatment on the surface topography of the fibres as observed through SEM. Rougher surface was observed on fibres treated from 2 to 6 wt.% NaOH. However, at 8 and 10 wt.% NaOH, significant deterioration was detected on the condition of the fibres, indicating that the concentration of alkali is too strong thus weakening the fibres. Based on this observation and supported by other literatures, 6% NaOH was selected as the optimal concentration for composite fabrication.

2. From the compressive test, it was observed that the addition of fibres to the gypsum matrix have improved its compressive strength and resulted in reduced brittleness. However, an optimum fibre volume fraction is identified for both sets of composites whereby the highest compressive strength is achieved at this volume percentage. For sisal fibre-gypsum composite, the optimum fibre content is at 25 vol.% while for glass fibre-gypsum composite, the optimum fibre content is at 30 vol.%. At higher fibre contents, both composites suffer a decrease in strength indicating that the fibres are no longer effective in reinforcing the gypsum.

3. Generally, the sisal fibre-gypsum composites perform better in compression as compared to the glass fibre-gypsum composites. However, the maximum strength was achieved by the composites with 30 vol.% of glass fibres.

4. From the thermal conductivity study, pure gypsum was found to have the highest thermal conductivity. The thermal conductivity of the composites decrease with the increment of fibre volume fraction.

5. Sisal fibre-gypsum composites performs slightly better at insulating heat as compared to glass fibre-gypsum composites possibly due to its porous nature, as heat transfer is impeded by the presence of air voids.

6. From this result, in terms of mechanical and thermal insulating properties, it can be concluded that using sisal fibres as reinforcement on gypsum produces composites suitable for wall panelling in buildings.

5.2 Recommendations

Since the work is at the initial stage, there are many research areas need to be addressed owing to further understand the heat conductivity of such materials. Some of the recommendations are as follows:

1. Influence of the inner structure of the materials on the heat conductivity needs to be understood since this may impact on the heat conductivity of the materials.

2. Different insulation materials can be compared with the current one for commercialization purposes.

3. Numerical study can be performed for simulation purposes and to visualize the heat dissipation in the materials.

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APPENDIX A: Project Specification

For	**Rashed Alajmi**
Topic	Study on the sisal fibres as insulator in building materials
Supervisor	Dr Belal Yousif
Enrolment	ENG 4111-S1, 2015 ENG 4112-S2, 2015
Project Aim	1. To investigate the heat conductivity of different wall composite materials based on different contents of Sisal fibres. 2. Study the bending, compressive and tensile behaviour of the developed materials 3. Examine the damage feature on the broken samples after each test
Sponsorship	Nil

Programme

1. Build the background of the project through reading articles and writing the literature
2. Prepare the sisal fibres
3. Fabrication of the sisal/wall materials samples.
4. Conduct the experiments, conductivity and compressive strength
5. Observe the damages on the samples
6. Analysis the results.
7. Optimize the performance of the materials.
8. Writing the final report and recommendations

Agreed

RASHED ALAJMI (Student) ,

BFY (Supervisor)

APPENDIX B: Project Timeline

Project Schedule:

Milestone Year		2016											
		January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
-	Project specifications												
1	**Literature Review**												
2	**Preliminary Study**												
2.1	Materials Selection												
2.2	Fibre treatment												
2.3	Fibre Morphology												
3	**Fibre preparation**												
4	**Composites fabrication**												
4.1	Develop of new setup												
4.2	Compressive test												
4.3	Thermal conductivity test												
5	**Preparing partial dissertation**												
6	**Analysis of results**												
7	**Comparison study**												
8	**Conclusion and recommendation**												
9	**Final dissertation**												

APPENDIX C: Resource Requirement Plan

Resource Requirement Plan for this research project

Requirement List research equipment, travel, proofreading and editing of dissertation, etc.	Date/ Month required	Estimated Purchase Amount (i.e. if not available at USQ/Centre)
1. Materials laboratory, compressive test laboratory, civil laboratory, and workshop.	March- September	Available at USQ, risk assessment sheets required prior to start use the laboratory.
2. Oven laboratory, SEM laboratory, precise scale, scissors, containers and hammer.	March- September	Available at USQ. Also, signature required before each use of the laboratory.
3. Raw Sisal fibers.	Approx. 5 to 20 of March	$300 AUD, Import from overseas (e.g. Kuwait).
4. Glass fibers.	Approx. 5 to 10 of March	$35 AUD, available at Bunnings Warehouse, Toowoomba.
5. Gypsum	Approx. 5 to 10 of March	$28.21 AUD, also, available at Bunnings Warehouse, Toowoomba.

6. mould release	During the fabrication of samples	Available at USQ, materials laboratory.
7. PVC pipe, insulator cover.	Approx. 5 to 10 March	Approx. $40 AUD, Available at Masters Warehouse, Toowoomba.
8. Heat gun, wooden board, thermocouples, metal cover.		Available at USQ, materials laboratory, workshop
9. Conference	March – September	Might be useful if there is a conference related to this study during the specified date.
10. Proofreading	September – October	Approx. $300 AUD
Total		Approx. $703.21 AUD, might be go up or less depends on any updates.

APPENDIX D: Risk Assessment

University of Southern Queensland
Risk Management Plan

http://www.usq.edu.au/hr/healthsafe/safetyproc/whsmanual/whsmanr1.htm

Date: 4 August 2015	**Faculty/Dept:** Engineering	**Assessment completed by:** Belal Yousif Rashed F. Alajmi	**Contact No:** 5331 0499293248
What is the task? **1- Fibre treatment using alkali solution** **2- Fabrication of composites**		**Location where task is being conducted:** Z106	
Why is the task being conducted? **Under graduate student research project.**			
What are the nominal conditions?			
Personnel **Students** Rashed alajmi	**Equipment** Hand tools NaOH Solution Plaster-Based Cement Preparation	**Environment** Air condition	**Other**
Briefly explain the procedure for this task (incl. Ref to other procedures) 1- Treating the raw sisal fibres with sodium hydroxide (NaOH) at low concentration level of less than 10%. **2-** Fabricating the samples using gyprock base coat 45, with sisal and glass fibres.			

Risk Register and Analysis

[ALARP = As Low As Reasonably Practicable]

Element or Sub Element/ Process Step	The Risk: What can happen and what will be the result	EXISTING CONTROLS	Risk Rating with existing controls? *See next page*			Is it ALARP? Yes/No	ADDITIONAL CONTROLS REQUIRED	Risk Rating with additional controls?			Is it ALARP? Yes/No	Risk Decision: Accept Transfer Treat
			Consequences	Likelihood	Rating			Consequences	Likelihood	Rating		
– List major steps or tasks in process	– Electric shock – Eye infection – Fire / explosion – Physical injury – Cut / graze – Chemical burn	List all current controls that are already in place or that will be used to undertake the task eg – List of Personal Protective Equipment (PPE) – Identify types facility, location – Existing safety measurers – Existing emergency procedures					Additional controls may be required to reduce risk rating eg – Greater containment (PC2) – Additional PPE – gloves safety glasses – Specific induction / training					
Prepare the NaOH solution	Solution may spill on hand or clothes	Wearing eye protection during process. Gloves is a MUST all the time of the preparation. Mask is a MUST all the time of the preparation Fume cabinet and eye wash available in room Training and safety induction provided to students Emergency procedures are in place.	2	D	L	YES	NA	NA	NA	NA	NA	**Accept**

Element or Sub Element/ Process Step	The Risk: What can happen and what will be the result	EXISTING CONTROLS	Risk Rating with existing controls? *See next page*			Is it ALARP? Yes/No	ADDITIONAL CONTROLS REQUIRED	Risk Rating with additional controls?			Is it ALARP? Yes/No	Risk Decision: Accept Transfer Treat
Placing the fibres in the solution	Solution may spill on hand or clothes	Wearing eye protection during process. All body should be covered Gloves is a MUST all the time of the preparation. Mask is a MUST all the time of the preparation Fume cabinet and eye wash available in room Training and safety induction provided to students Emergency procedures are in place	1	D	L	YES	NA	NA	NA	NA	NA	**Accept**
Remove the fibres from the solution and dispose the solution	Solution spill Solution smell	Wearing eye protection during process. All body should be covered Gloves is a MUST all the time of the preparation. Mask is a MUST all the time of the preparation Fume cabinet and eye wash available in room Training and safety induction provided to students Emergency procedures are in place	2	D	L	YES	N/A	N/A	N/A	N/A	N/A	**Accept**

Element or Sub Element/ Process Step	The Risk: What can happen and what will be the result	EXISTING CONTROLS	Risk Rating with existing controls? *See next page*			Is it ALARP? Yes/No	ADDITIONAL CONTROLS REQUIRED	Risk Rating with additional controls?			Is it ALARP? Yes/No	Risk Decision: Accept Transfer Treat
CSR Plaster-Based Cement preparation	Irritating to eyes, respiratory system and skin	Wearing eye protection during process. All body should be covered Gloves is a MUST all the time of the preparation. Mask is a MUST all the time of the preparation Fume cabinet and eye wash available in room . Training and safety induction provided to students Emergency procedures are in place	1	D	L	YES	NA	NA	NA	NA	NA	**Accept**
Preparation of the samples	The mixture of the plaster and the fibre may adhered into the hand	Wearing eye protection, hand gloves, Chemical respirator during process. Fume cabinet and eye wash available in room Training and safety induction provided to students Emergency procedures are in place.	2	D	L	YES	N/A	N/A	N/A	N/A	N/A	**Accept**

Risk Treatment Schedule

Risk No	Risk	Treatment	Person Responsible for Implementation	Timetable for Implementation	Date Treatment Completed	Review of Effectiveness Effective/Not effective

Notes

The task should not proceed if the risk rating after the controls are implemented is still either HIGH or EXTREME or if any risk is not As Low As Reasonably Practicable (ALARP).

This Risk Assessment score of Low (L) is only on the condition that all existing and additional controls are in place at the time of the task being conducted.

Assessment completed by:

Name: Rashed F. Alajmi

Signature:

Position: Student

Contact No: 0499293248

Date: 4 august 2015

Supervisor or Designated Officer

Name: Belal Yousif

Signature:

Position: Associate Prof.

Contact No: 46315331

Date: 4 August 2015

Safety Coordinator

Name:

Signature:

Position:

Contact No:

Date:

Review of Controls:

This Risk Management Plan is to be reviewed not later than seven (7) days after the commencement of the project and then every twelve (12) months and whenever a change has been made to the project or workplace.

Supervisor or Designated Officer

Name: Signature:

Position: Contact No:

Date of Review:

Safety Coordinator

Name: Signature:

Position: Contact No:

Date of Review:

Review of this Risk Management Plan:
This Risk Management Plan is to be reviewed every twelve (12) months and whenever a change has been made to the project or workplace.

Date due Review: …….

Supervisor or Designated Officer

Name: Signature:

Position: Contact No:

Date of Review:

Safety Coordinator

Name: Signature:

Position: Contact No:

Date of Review:

University of Southern Queensland
Risk Management Plan

http://www.usq.edu.au/hr/healthsafe/safetyproc/whsmanual/whsmanr1.htm

Date: 4 August 2015	**Faculty/Dept:** Engineering	**Assessment completed by:** Belal Yousif Rashed F. Alajmi	**Contact No:** 5331 0499293248
What is the task? **Compressive test for the composites**		**Location where task is being conducted:** Block z, mechanical testing laboratory	
Why is the task being conducted? **Under graduate student research project.**			
What are the nominal conditions?			
Personnel **Students** Rashed alajmi	**Equipment** MTS 647 Hydraulic Wedge Grip with a 100 kN maximum capacity	**Environment** Air condition	**Other**
Briefly explain the procedure for this task (incl. Ref to other procedures) The samples will be placed in the compressive test machine until failure.			

Risk Register and Analysis

[ALARP = As Low As Reasonably Practicable]

Element or Sub Element/ Process Step	The Risk: What can happen and what will be the result	EXISTING CONTROLS	Risk Rating with existing controls? *See next page*			Is it ALARP? Yes/No	ADDITIONAL CONTROLS REQUIRED	Risk Rating with additional controls?			Is it ALARP? Yes/No	Risk Decision: Accept Transfer Treat
– List major steps or tasks in process	– Electric shock – Eye infection – Fire / explosion – Physical injury – Cut / graze – Chemical burn	List all current controls that are already in place or that will be used to undertake the task eg – List of Personal Protective Equipment (PPE) – Identify types facility, location – Existing safety measurers – Existing emergency procedures	Consequences	Likelihood	Rating		Additional controls may be required to reduce risk rating eg – Greater containment (PC2) – Additional PPE – gloves safety glasses – Specific induction / training	Consequences	Likelihood	Rating		
Turn on the MTS 647 machine	Electrical shock	Leather gloves Trained personnel operates machine / Task is supervised. Risk Management Plan (RMP) has been developed and is readily available. Emergency procedures are in place.	3	E	L	YES	NA	NA	NA	NA	NA	**Accept**

Element or Sub Element/ Process Step	The Risk: What can happen and what will be the result	EXISTING CONTROLS	Risk Rating with existing controls? *See next page*			Is it ALARP? Yes/No	ADDITIONAL CONTROLS REQUIRED	Risk Rating with additional controls?			Is it ALARP? Yes/No	Risk Decision: Accept Transfer Treat
Placing the sample fixtures of the machine	Hand and feet injuries	Fixtures are manually placed into position by trained personnel/ Task is supervised. Wearing of safety shoes and gloves The trained personnel will operate machine. Standard Work Procedures (SWP) have been developed and is readily available. Risk Management Plan (RMP) has been developed and is readily available. Emergency procedures are in place.	2	D	L	YES	NA	NA	NA	NA	NA	**Accept**
Placing the composites on the machine	Pinching Crushing	Wearing safety gloves Ensure the machine is turn off before placing the samples	2	D	L	Yes	N/A	N/A	N/A	N/A	N/A	**Accept**

Element or Sub Element/ Process Step	The Risk: What can happen and what will be the result	EXISTING CONTROLS	Risk Rating with existing controls? *See next page*			Is it ALARP? Yes/No	ADDITIONAL CONTROLS REQUIRED	Risk Rating with additional controls?			Is it ALARP? Yes/No	Risk Decision: Accept Transfer Treat
Perform the load testing	Debris could fly from the fracture of the specimen Dust exposure Debris on the floor creates a slip.	Wearing eye protection during the testing process or stay behind the safety screen. Wearing dust mask Wearing safety footwear Standard Work Procedures (SWP) have been developed and is readily available. Risk Management Plan (RMP) has been developed and is readily available. Task is supervised by trained personnel. Emergency procedures are in place. Wearing dust mask	2	E	L	YES	NA	NA	NA	NA	NA	**Accept**
Removing the tested samples from the machine	Pinching Crushing Sharp fractured samples	Wearing safety gloves Ensure the machine is turn off before removing the samples	3	E	L	Yes	N/A	N/A	N/A	N/A	N/A	**Accept**

Element or Sub Element/ Process Step	The Risk: What can happen and what will be the result	EXISTING CONTROLS	Risk Rating with existing controls? *See next page*			Is it ALARP? Yes/No	ADDITIONAL CONTROLS REQUIRED	Risk Rating with additional controls?			Is it ALARP? Yes/No	Risk Decision: Accept Transfer Treat
Turning off the machine	Electrical shock	Leather gloves Trained personnel operates machine / Task is supervised. Risk Management Plan (RMP) has been developed and is readily available.	3	E	L	Yes	N/A	N/A	N/A	N/A	N/A	**Accept**

Risk Treatment Schedule

Risk No	Risk	Treatment	Person Responsible for Implementation	Timetable for Implementation	Date Treatment Completed	Review of Effectiveness Effective/Not effective

Notes

The task should not proceed if the risk rating after the controls are implemented is still either HIGH or EXTREME or if any risk is not As Low As Reasonably Practicable (ALARP).

This Risk Assessment score of Low (L) is only on the condition that all existing and additional controls are in place at the time of the task being conducted.

Assessment completed by:

Name: Rashed F. Alajmi

Signature:

Position: Student

Contact No: 0499293248

Date: 4 august 2015

Supervisor or Designated Officer

Name: Belal Yousif

Signature:

Position: Associate Prof.

Contact No: 46315331

Date: 4 August 2015

Safety Coordinator

Name:

Signature:

Position:

Contact No:

Date:

Review of Controls:
This Risk Management Plan is to be reviewed not later than seven (7) days after the commencement of the project and then every twelve (12) months and whenever a change has been made to the project or workplace.

Supervisor or Designated Officer

Name: Signature:

Position: Contact No:

Date of Review:

Safety Coordinator

Name: Signature:

Position: Contact No:

Date of Review:

Review of this Risk Management Plan:
This Risk Management Plan is to be reviewed every twelve (12) months and whenever a change has been made to the project or workplace.

Date due Review: …….

Supervisor or Designated Officer

Name: Signature:

Position: Contact No:

Date of Review:

Safety Coordinator

Name: Signature:

Position: Contact No:

Date of Review:

University of Southern Queensland
Risk Management Plan

http://www.usq.edu.au/hr/healthsafe/safetyproc/whsmanual/whsmanr1.htm

Date: 4 August 2015	**Faculty/Dept:** Engineering	**Assessment completed by:** Belal Yousif Rashed F. Alajmi	**Contact No:** 5331 0499293248
What is the task? **Thermal conductivity test for the composites**		**Location where task is being conducted:** ……	
Why is the task being conducted? **Under graduate student research project.**			
What are the nominal conditions?			
Personnel **Students** Rashed Alajmi	**Equipment** Makita heat Gun Thermocouples Wooden board	**Environment** Well ventilated open area	**Other**
Briefly explain the procedure for this task (incl. Ref to other procedures) The samples will be heated at 100 degree C.			

Risk Register and Analysis

[ALARP = As Low As Reasonably Practicable]

Element or Sub Element/ Process Step	The Risk: What can happen and what will be the result	EXISTING CONTROLS	Risk Rating with existing controls? *See next page*			Is it ALARP? Yes/No	ADDITIONAL CONTROLS REQUIRED	Risk Rating with additional controls?			Is it ALARP? Yes/No	Risk Decision: Accept Transfer Treat
– List major steps or tasks in process	– Electric shock – Eye infection – Fire / explosion – Physical injury – Cut / graze – Chemical burn	List all current controls that are already in place or that will be used to undertake the task eg – List of Personal Protective Equipment (PPE) – Identify types facility, location – Existing safety measurers – Existing emergency procedures	Consequences	Likelihood	Rating		Additional controls may be required to reduce risk rating eg – Greater containment (PC2) – Additional PPE – gloves safety glasses – Specific induction / training	Consequences	Likelihood	Rating		
Turn on the heat gun	Electrical shock	Leather gloves Operate away from water source Emergency procedures are in place.	2	E	L	YES	NA	NA	NA	NA	NA	**Accept**
Placing the sample in the sample holder	Hand injuries	. Wearing of safety shoes and gloves	2	D	L	YES	NA	NA	NA	NA	NA	**Accept**

Element or Sub Element/ Process Step	The Risk: What can happen and what will be the result	EXISTING CONTROLS	Risk Rating with existing controls? *See next page*			Is it ALARP? Yes/No	ADDITIONAL CONTROLS REQUIRED	Risk Rating with additional controls?			Is it ALARP? Yes/No	Risk Decision: Accept Transfer Treat
Performing the heat conductivity test	Indirect burning caused by unwanted interaction between the heat gun and metallic sample holder Direct burning from touching the samples	Wearing of safety gloves and shoes Always keep the door shut and locked to prevent unauthorised Access or tampering.	2	D	L	Yes	N/A	N/A	N/A	N/A	N/A	**Accept**
Turn off the heat gun	Electrical shock	Leather gloves Operate away from water source Emergency procedures are in place.	2	D	L	Yes	N/A	N/A	N/A	N/A	N/A	Accept
Removing the samples from the sample holder	Indirect burning caused by unwanted interaction between the heat gun and metallic sample holder Direct burning from touching the samples	Wearing of safety gloves and shoes Ensure the samples are cooled before removing it	2	D	L	Yes	N/A	N/A	N/A	N/A	N/A	**Accept**

Risk Treatment Schedule

Risk No	Risk	Treatment	Person Responsible for Implementation	Timetable for Implementation	Date Treatment Completed	Review of Effectiveness Effective/Not effective

Notes

The task should not proceed if the risk rating after the controls are implemented is still either HIGH or EXTREME or if any risk is not As Low As Reasonably Practicable (ALARP).

This Risk Assessment score of Low (L) is only on the condition that all existing and additional controls are in place at the time of the task being conducted.

Assessment completed by:

Name: Rashed F. Alajmi

Signature:

Position: Student

Contact No: 0499293248

Date: 4 august 2015

Supervisor or Designated Officer

Name: Belal Yousif

Signature:

Position: Associate Prof.

Contact No: 46315331

Date: 4 August 2015

Safety Coordinator

Name:

Signature:

Position:

Contact No:

Date:

Review of Controls:
This Risk Management Plan is to be reviewed not later than seven (7) days after the commencement of the project and then every twelve (12) months and whenever a change has been made to the project or workplace.

Supervisor or Designated Officer

Name: Signature:

Position: Contact No:

Date of Review:

Safety Coordinator

Name: Signature:

Position: Contact No:

Date of Review:

Review of this Risk Management Plan:
This Risk Management Plan is to be reviewed every twelve (12) months and whenever a change has been made to the project or workplace.

Date due Review: …….

Supervisor or Designated Officer

Name: Signature:

Position: Contact No:

Date of Review:

Safety Coordinator

Name: Signature:

Position: Contact No:

Date of Review:

Guidance Notes for review of Controls and Risk Management Plan.

When monitoring the effectiveness of **control measures**, it may be helpful to ask the following questions:

- **Have the chosen control measures been implemented as planned?**
  - Are the chosen control measures in place?
  - Are the measures being used?
  - Are the measures being used correctly?
- **Are the chosen control measures working?**
  - Have any the changes made to manage exposure to the assessed risks resulted in what was intended?
  - Has exposure to the assessed risks been eliminated or adequately reduced?
  - **Are there any new problems?**
  - Have the implemented control measures introduced any new problems?
  - Have the implemented control measures resulted in the worsening of any existing problems?

To answer these questions:

- consult with workers, supervisors and health and safety representatives;
- measure people's exposure (e.g. taking noise measurements in the case of isolation of a noise source);
- consult and monitor incident reports; and
- review safety committee meeting minutes where possible.

Set a date for the review of the **risk management process**. When reviewing, check if:

- the process that is currently in place is still valid;
- things have changed that could make the operating processes or system outdated;
- technological or other changes have affected the current workplace; and
- a different system should be used altogether.

USQ RISK RATING ADAPTED FROM AS4360:2004

Note: In estimating the level of risk, initially estimate the risk with existing controls and then review risk controls if risk level arising from the risks is not minimal

TABLE 1 - CONSEQUENCE

Level	Descriptor	Examples of Description
1	Insignificant	No injuries. Minor delays. Little financial loss. $0 - $4,999*
2	Minor	First aid required. Small spill/gas release easily contained within work area. Nil environmental impact. Financial loss $5,000 - $49,999*
3	Moderate	Medical treatment required. Large spill/gas release contained on campus with help of emergency services. Nil environmental impact. Financial loss $50,000 - $99,999*
4	Major	Extensive or multiple injuries. Hospitalisation required. Permanent severe health effects. Spill/gas release spreads outside campus area. Minimal environmental impact. Financial loss $100,000 - $250,000*
5	Catastrophic	Death of one or more people. Toxic substance or toxic gas release spreads outside campus area. Release of genetically modified organism (s) (GMO). Major environmental impact. Financial loss greater than $250,000*

* Financial loss includes direct costs eg workers compensation and property damage and indirect costs, eg impact of loss of research data and accident investigation time.

TABLE 2 - PROBABILITY

Level	Descriptor	Examples of Description
A	Almost certain	The event is expected to occur in most circumstances. Common or repetitive occurrence at USQ. Constant exposure to hazard. Very high probability of damage.
B	Likely	The event will probably occur in most circumstances. Known history of occurrence at USQ. Frequent exposure to hazard. High probability of damage.
C	Possible	The event could occur at some time. History of single occurrence at USQ. Regular or occasional exposure to hazard. Moderate probability of damage.
D	Unlikely	The event is not likely to occur. Known occurrence in industry. Infrequent exposure to hazard. Low probability of damage.
E	Rare	The event may occur only in exceptional circumstances. No reported occurrence globally. Rare exposure to hazard. Very low probability of damage. Requires multiple system failures.

USQ RISK RATING ADAPTED FROM AS4360:2004

TABLE 3 – RISK RATING

Probability	Consequence				
	Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
A (Almost certain)	M	H	E	E	E
B (Likely)	M	H	H	E	E
C (Possible)	L	M	H	H	H
D (Unlikely)	L	L	M	M	M
E (Rare)	L	L	L	L	L

Recommended Action Guide:

Abbrev	Action Level	Descriptor
E	Extreme	The proposed task or process activity MUST NOT proceed until the supervisor has reviewed the task or process design and risk controls. They must take steps to firstly eliminate the risk and if this is not possible to introduce measures to control the risk by reducing the level of risk to the lowest level achievable. In the case of an existing hazard that is identified, controls must be put in place immediately.
H	High	Urgent action is required to eliminate or reduce the foreseeable risk arising from the task or process. The supervisor must be made aware of the hazard. However, the supervisor may give special permission for staff to undertake some high risk activities provided that system of work is clearly documented, specific training has been given in the required procedure and an adequate review of the task and risk controls has been undertaken. This includes providing risk controls identified in Legislation, Australian Standards, Codes of Practice etc.* A detailed Standard Operating Procedure is required. * and monitoring of its implementation must occur to check the risk level
M	Moderate	Action to eliminate or reduce the risk is required within a specified period. The supervisor should approve all moderate risk task or process activities. A Standard Operating Procedure or Safe Work Method statement is required
L	Low	Manage by routine procedures.

*Note: These regulatory documents identify specific requirements/controls that must be implemented to reduce the risk of an individual undertaking the task to a level that the regulatory body identifies as being acceptable.

APPENDIX E: Material Safety Data Sheet

GYPROCK™
Everything else is just plasterboard

CSR SAFETY DATA SHEET
CSR Plaster-Based Cements and Adhesives

SECTION 1: IDENTIFICATION OF THE MATERIAL AND SUPPLIER

Product Name:	**CSR Plaster-Based Cements and Adhesives**
Other Names:	Gyprock Base Coat 20/45/60/90, Gyprock Cornice Cement, Gyprock Cornice Cement 45/60, Gyprock Drywall Adhesive 100, Gyprock Masonry Adhesive, Gyprock Patching Cement, Gyprock Back Blocking Cement, Gyprock Rapid Patch, Gyprock Rapid Set
Product Codes/Trade Names:	n/a
Recommended Use:	Adhesive, jointing cement, patching compound
Applicable In:	Australia
Supplier:	CSR Building Products Limited ABN 55 008 631 356
Address:	Triniti 3, 39 Delhi Road, North Ryde, NSW 2113, Australia
Telephone:	+61 2 9235 8000 (or 1800 807 668 (available in Australia only))
Email Address:	http://www.csr.com.au/Pages/Contact-Us.aspx
Web Site:	www.csr.com.au
Facsimile:	+61 2 9372 5819
Emergency Phone Number:	000 Fire Brigade and Police (available in Australia only)
Poisons Information Centre:	13 11 26 (available in Australia only)

This Safety Data Sheet (SDS) is issued by the Supplier in accordance with National standards and guidelines from Safe Work Australia (SWA – formerly ASCC/NOHSC). The information in it must not be altered, deleted or added to. The Supplier will not accept any responsibility for any changes made to its SDS by any other person or organization. The Supplier will issue a new SDS when there is a change in product specifications and/or standards, codes, guidelines, or Regulations.

SECTION 2: HAZARD IDENTIFICATION

STATEMENT OF HAZARDOUS NATURE: Classified as **Non-Hazardous** according to the criteria of Safe Work Australia (SWA – formerly ASCC/NOHSC) Approved Criteria For Classifying Hazardous Substances [NOHSC:1008] 3rd Edition.

Plaster-Based Cements and Adhesives is classified as **Non-Dangerous** Goods according to the Australian Code for the Transport of Dangerous Goods by Road and Rail.

Cutting, breaking, drilling, sawing, grinding and finishing may generate dust (calcium sulphate) which is classified as **Hazardous.** The following Risk and Safety phrases apply to airborne dust of this product:

Risk Phrases	Safety Phrases
R36/37/38: Irritating to eyes, respiratory system and skin.	**S22:** Do not breathe dust.
R66: Repeated exposure may cause skin dryness or cracking.	**S24/25:** Avoid contact with skin and eyes.
	S36/37/39: Wear suitable protective clothing, gloves and eye/face protection.

SECTION 3: COMPOSITION / INFORMATION ON INGREDIENTS

Chemical Name:	Synonyms:	Proportion:	CAS Number:
Calcium sulphate hemihydrate	Gypsum	65-98%	10034-76-1
Calcium carbonate	Chalk	<31%	1317-65-3
Mica	N/A	<10%	12001-26-2
Perlite	N/A	<10%	93763-70-3
Talc	N/A	<3%	14807-96-6
Ethylene vinyl acetate copolymer	N/A	<2%	24937-78-8
Calcium hydroxide	N/A	<2%	1305-62-0
Polyvinyl alcohol	PVA	<2%	9002-89-5
Starch	N/A	<2%	9005-25-8

Note: The crystalline silica (quartz) content (if any) is less than 0.1%.

SECTION 4: FIRST AID MEASURES

Swallowed:	Rinse mouth and lips with water. Do not induce vomiting.
Eyes:	Flush thoroughly with flowing water, while holding eyelids open, for 15 minutes to remove all traces.
Skin:	Wash off skin thoroughly with water. Use a mild soap if available.
Inhaled:	Remove to fresh air. If symptoms persist, seek medical attention.
Advice to Doctor:	Treat symptomatically.

SECTION 5: FIRE FIGHTING MEASURES

Flammability:	Non-flammable
Suitable extinguishing media:	Use carbon dioxide, foam, dry chemical or water spray to extinguish, as required for fire in surrounding materials.
Hazards from combustion products:	None
Special protective precautions and equipment for fire fighters:	None
HAZCHEM Code:	None

SECTION 6: ACCIDENTAL RELEASE MEASURES

Clean Up Procedure:	Dust and waste should be cleaned up by bagging, wet sweeping and/or vacuuming.

SECTION 7: HANDLING AND STORAGE

Handling:	Manual handling should be in accordance with Manual Handling Regulations and Codes.
Storage:	This product should be stored in its factory packaging in a dry area.
Incompatibilities:	Incompatible with aluminium, strong acids.

SECTION 8: EXPOSURE CONTROLS / PERSONAL PROTECTION

Workplace Exposure Standards:	**Workplace Exposure Standards for Airborne Contaminants, Safe Work Australia** Calcium sulphate: TWA - 10 mg/m^3 as inspirable dust Total dust (of any type, or particle size): TWA - 10 mg/m^3
Notes on Exposure Standards:	All occupational exposures to atmospheric contaminants should be kept to as low a level as is workable (practicable) and in all cases to below the Workplace Exposure Standard (WES). TWA (Time Weighted Average): the time-weighted average airborne concentration over an eight-hour working day, for a five-day working week over an entire working life. According to current knowledge this concentration should neither impair the health of, nor cause undue discomfort to, nearly all workers.
Biological Limit Values:	No biological limit allocated.
ENGINEERING CONTROLS	
☐ **Ventilation:**	Keep exposures to dust as low as practicable. General room ventilation should be adequate, but local mechanical ventilation may be required if dust is generated, particularly in confined spaces. If engineering controls and work practices are not effective in controlling dust, then personal protective equipment may be required.
☐ **Special Consideration for Repair &/or Maintenance of Contaminated Equipment:**	Work areas should be cleaned regularly by damp sweeping or vacuuming. Recommendations on Exposure Control and Personal Protection should be followed.
PERSONAL PROTECTION	
☐ **Personal Hygiene**	Wash work clothes regularly. Wash hands before eating, drinking, using the toilet, or smoking.
☐ **Skin Protection:**	Wear loose comfortable clothing. Direct skin contact should be avoided by wearing long sleeved shirts and long trousers, a cap or hat, and gloves (standard duty leather or equivalent AS 2161).
☐ **Eye Protection:**	Ventilated non-fogging goggles (dust resistant AS/NZS 1336) should be worn when working in a dusty environment.
☐ **Respiratory Protection:**	None required if engineering and handling controls are adequate. Where engineering and handling controls are not enough to minimise exposure to total dust, personal respiratory protection may be required. The type of respiratory protection required depends primarily on the concentration of dust in the air, and the frequency and length of exposure time. Amount of exertion required during the work, and personal comfort are other considerations in choice of respirator. A suitable P1 or P2 particulate respirator chosen and used in accordance with AS/NZS 1715 and AS/NZS 1716 may be sufficient for many situations, but where high levels of dust are encountered, more efficient cartridge-type or powered respirators or supplied-air helmets or suits may be necessary. Use only respirators that bear the Australian Standards mark and are fitted and maintained correctly, and kept in clean storage when not in use.

SECTION 9: PHYSICAL AND CHEMICAL PROPERTIES

Appearance:	Off white powder
Odour:	Slight plaster odour

pH, at stated concentration:	7.5 - 8.5
Vapour Pressure:	Not applicable
Vapour Density:	Not applicable
Boiling Point/Range (°C):	Not determined
Melting Point (°C):	1450°C (Calcium sulphate)
Solubility in water	Insoluble
Specific Gravity (H_2O = 1):	2.3 - 2.4
FLAMMABLE MATERIALS	
☐ **Flash Point:**	Not applicable
☐ **Flash Point Method:**	Not applicable
☐ **Flammable (Explosive) Limit - Upper:**	Not applicable
☐ **Flammable (Explosive) Limit - Lower:**	Not applicable
☐ **Auto ignition Temperature:**	Not applicable
ADDITIONAL PROPERTIES	
☐ **Evaporation Rate:**	Not applicable
☐ **% Volatiles:**	0%
☐ **Volatile Organic Compounds Content (VOC):** (as specified by the Green Building Council of Australia)	0%

SECTION 10: STABILITY AND REACTIVITY

Chemical Stability:	Stable
Incompatible Materials:	Incompatible with aluminium, strong acids.
Conditions to avoid:	None
Hazardous Decomposition Products:	Releases oxides of sulphur when heated to decomposition.
Hazardous Reactions:	None

SECTION 11: TOXICOLOGICAL INFORMATION

Toxicology data: Not available on this product, but anticipated to be very low with LD50 >5000 mg/kg.

Health Effects: Acute (short term)

Swallowed:	Unlikely under normal industrial use, but swallowing may result in nausea or abdominal discomfort.
Eyes:	Dust is irritating to the eyes causing watering and redness. Exposure to dust may aggravate pre-existing eye conditions.
Skin:	The dust from this product, particularly in association with heat and sweat, may cause mild irritation and drying to the skin due to its physical characteristics.

Inhaled:	Can cause irritation of the nose, throat and lungs resulting in excess mucus and coughing.

Health Effects: Chronic (long term)

Eyes:	Dust may cause irritation and inflammation of the eyes and aggravate pre-existing eye conditions.
Skin:	Repeated heavy contact with the dust may cause drying of the skin and can result in skin rash (dermatitis) typically affecting the hands. Over time this may become chronic and can also become infected.
Inhaled:	Repeated exposure to the dust may result in increased nasal and respiratory secretions and coughing. Inhaling dust may aggravate pre-existing respiratory conditions.

SECTION 12: ECOLOGICAL INFORMATION

Eco-toxicity:	The physical and chemical nature of the product, and toxicological data on ingredients, indicate that this product is a relatively low risk.
Persistence and Degradability:	Product is persistent and would have a low degradability.
Mobility:	A low mobility would be expected in a landfill situation.

SECTION 13: DISPOSAL CONSIDERATIONS

Waste should be placed in containers and disposed of with other construction waste in accordance with local authority guidelines. Measures should be taken to prevent dust generation during disposal and exposure and personal precautions should be observed (see Section 8).

SECTION 14: TRANSPORT INFORMATION

Proper Shipping Name:	None allocated
UN number:	None allocated
DG Class:	None allocated
Subsidiary Risk 1:	None allocated
Packaging Group:	None allocated
HAZCHEM code:	None allocated
Marine Pollutant:	No

SECTION 15: REGULATORY INFORMATION

Poisons Schedule:	Not scheduled

SECTION 16: OTHER INFORMATION

For further information on this product, please contact:

CSR Building Products Limited (ABN 55 008 631 356), Triniti 3, 39 Delhi Road, North Ryde, NSW 2113, Australia

Phone: +61 2 9372 5888 or 1800 807 668 (available in Australia only)

Fax: +61 2 9372 5877

ADDITIONAL INFORMATION

Australian Standards References:

AS/NZS 1336	Recommended Practices for Occupational Eye Protection
AS/NZS 1715	Selection, Use and Maintenance of Respiratory Protective Devices
AS/NZS 1716	Respiratory Protective Devices
AS 2161	Industrial Safety Gloves and Mittens (excluding electrical and medical gloves)

Other References:

NOHSC:1008 (2004)	Approved Criteria for Classifying Hazardous Substances
Model Code of Practice	Preparation of Safety Data Sheets for Hazardous Chemicals, December 2011, Safe Work Australia.
Model Code of Practice	Labelling of Workplace Hazardous Chemicals, December 2011, Safe Work Australia.
Model Code of Practice	Managing Risks Of Hazardous Chemicals In The Workplace, July 2012, Safe Work Australia.
ADG Code	Australian Code for the Transport of Dangerous Goods by Road and Rail, 7th edition, National Transport Commission.
WES	Workplace Exposure Standards For Airborne Contaminants, April 2013, Safe Work Australia.
WES	Guidance On The Interpretation Of Workplace Exposure Standards For Airborne Contaminants, April 2013, Safe Work Australia.
GHS	Globally Harmonized System of Classification and Labelling of Chemicals (GHS), 5th revised edition, United Nations, New York and Geneva, 2013.
HSIS	Hazardous Substances Information System (HSIS), internet advisory service, Safe Work Australia.

AUTHORISATION

Reason for Issue:	Periodic review and update
Authorised by:	Peter Tollens
Date of Issue:	29/01/2015

END OF SDS

Gyprock® Product Datasheet

Gyprock® Base Coat 45

Gyprock Base Coat 45 is a specially formulated base compound used for the first and second coat in a three coat plasterboard jointing system. Joints may be finished with any Gyprock topping or all-purpose compound and sanded smooth prior to decoration.

Gyprock Base Coats help to create a superior strength joint in conjunction with jointing tape and provide excellent tape adhesion.

Base Coat 45 is a low VOC dry powder compound, manufactured by Gyprock in Australia to stringent product specifications and is packed in blue coloured bags.

First and Second Coats

The formulation of Base Coat 45 gives it superior tape adhesion and joint strength for the tape coat and second coat in the jointing process.

Defined Setting Time

Base Coat 45 is a setting compound not an evaporative drying type. It has a defined working life of approximately 45 minutes after mixing, allowing subsequent coating on the same day.

Hand and Machine Tool Applied

Base Coat 45 is easy to trowel and feather with hand tools, mud boxes, automatic tapers and other machine tools.

Product Options

Nationally - Gyprock Base Coat 45 is available in dry powder form in 10kg and 20kg bags.

Vic & Tas – a 6kg bag is also available in these states

Application

First Coat

1. Fill recess evenly and fully with compound.
2. Bed in Gyprock Perforated Paper Tape centrally over the joint and cover lightly with compound. Apply at least 1mm thickness of compound under the tape.
3. Bed tapes to butt joints and internal corner angles. Apply at least 1mm thickness of compound under the tape.
4. Cover all metal corner beads and fastener heads.

5. Allow compound to set and harden for at least 60 minutes before recoating.

Second Coat

1. Apply a second coat of Gyprock Base Coat 45 to:

a. Recessed edge joints to a width of about 180mm.
b. Butt joints to a width of about 400mm.
c. Metal corner beads to a width of about 200mm.
d. Fastener heads.

2. Allow compound to set and harden for at least one hour before recoating. Ideally, the joint should be fully dry before the final coat is applied.

Third Coat

Apply a thin final coat of any Gyprock topping or all-purpose compound. Allow approximately 24 hours for it to dry, then sand to a smooth finish using 180 grit sandpaper or 220 grit sanding mesh.

More Installation Assistance

Comprehensive installation instructions for Gyprock plasterboard and compounds can be found under the Resources tab and include:

- DIY installation guides
- DIY installation videos
- Professional installation guides

For assistance with installation, try searching for a Gyprock plasterer, builder or repairer under the Locations tab.

Product Availability			
Weight	Pack	Coverage-Approx Qty/100m^2	Shelf Life
10kg	Blue bag	16kg	1 year from manufacture
20kg	Blue bag	16kg	1 year from manufacture
6kg (VIC & TAS only)	Blue bag	16kg	1 year from manufacture

To confirm product availability, please check with your local Gyprock supplier, or contact Gyprock customer service

Product Manufacture

Gyprock Base Coat 45 is manufactured by Gyprock in Australia to stringent product specifications.

Plasterboard Installation

AS/NZS2589: Gypsum linings – Application and Finishing outlines the procedures for jointing and finishing of Gyprock plasterboard in conjunction with additional details contained in Gyprock Technical Literature.

Levels of Finish

A Level of Finish sets out the minimum specifications for installation processes from framing preparation to painting and decoration. The levels are defined in AS/NZS 2589.1, and are intended to provide builders, installers and homeowners with defined methods and practices necessary to meet expectations in terms of the Level of Finish.

The level of finish should be specified prior to construction as it can be affected at different stages of construction and tolerances must be adhered to:

- Frame construction
- Plasterboard fixing and backblocking
- Plasterboard jointing and setting

A Level 3 Finish is for areas that do not require painting and decoration such as above ceilings and inside service shafts.

A Level 4 Finish is the generally accepted level for domestic construction

A level 5 Finish should be specified wherever gloss, semi-gloss or dark coloured paints are to be used, or where critical glancing light conditions are likely.

More information on Levels of Finish can be found in the Gyprock Residential Installation Guide

Painting and Decoration

Finishes applied to plasterboard surfaces can have a significant effect on the perceived quality of the installation, particularly where critical lighting conditions exist.

- Textured or heavy patterned finishes tend to hide imperfections
- Matt finishes minimise imperfection visibility
- Semi-gloss and gloss finishes highlight imperfections
- Light colours are less likely to show imperfections and impact damage

Gyprock recommends paint systems consisting of one coat of a plasterboard sealer followed by two coats of finishing paint. Always follow the manufacturer's instructions for application and recoating.

Gyprock recommends decoration in line with Master Painters Australia.

Physical and chemical properties	
Specific gravity (H_{20}=1)	2.3-2.4
VOC content (as specified by GBCA)	<10 grams per Litre as VOC content per material

Ingredients
Calcium Sulphate
Calcium Carbonate
Mica
Talc
Calcium Hydroxide

Material Safety

MSDS

A Material Safety Data Sheet for Gyprock Base Coat 45 is available from the Gyprock website under the Resources tab.

Handling and storage

For guidelines on the safe handling of Gyprock products, reference should be made to the Gypsum Board Manufacturers of Australasia (GBMA) publication *"Move it the GMBA Way – A Safe Manual Handling Guide for the Plasterboard Industry – Training Guide"* (Reference SS172).

This product should be stored in its factory packaging in a dry area.

Gyprock products are manufactured for life with all CSR products designed to achieve optimal performance when part of a CSR integrated system

All Gyprock jointing products exceed the GBCA specification for Volatile Organic Compound content according to independent testing. Test certificates are available under the Resources tab.

Gyprock® Base Coat 45 is accredited to the GECA AFSv4.0-2014 Adhesives, Fillers & Sealants Standard which is compliant with the requirements of the GBCA's Assessment Framework for product certification schemes.

Diggers Fibreglass Matting

Typical Characteristics

Appearance.....yellow and white fibres
Odour..... none
Specific Gravity..... 2.5–2.8
Melting Point..... >700°C

MSDS available

DESCRIPTION

Diggers Fibreglass Matting is designed for use with **Diggers Fibreglass Resin** and **Diggers Fibreglass Resin Catalyst** for general repairs.

TYPICAL USES

- Bikes, boats, castables, vacuum-cast shapes, automotive bodywork and surfboards

FEATURES

- 450 gsm
- Strand-chopped fibreglass matting for reinforcement
- Rough finish
- Yellow and white fibres bound together in strands
- Non-hazardous

APPLICATION

1. Prepare the surface with **Diggers Acetone**.
2. Cut the chopped strand mat to the required size and allow an extra centimetre around the edges. On tight curves, tear the mat to fit, adding extra pieces if needed. Put the mat on a clean surface until ready for use (e.g. newspaper).
3. Mix no more resin than what you can use in 30 minutes: 920ml (1kg) resin = 1m² matting; 460ml (500g) resin = 0.50m² matting; 230ml (250g) resin = 0.25m² matting.
4. Mix resin with catalyst: for 100ml resin (cold day) use 2.5 to 3ml catalyst; and 100ml resin (hot day) use 1.5 to 2ml catalyst. 1ml = 45 drops.
5. Brush a thick coat of resin onto the surface and then position the fibreglass on top of the wet resin. Add another coat of resin taking care not to displace the fibres. Dab it, do not brush it. Make sure that every part of the fibreglass is 'wet out' thoroughly (with no air bubbles). Allow to saturate and use a roller to squeeze the air out of the fibres. Clean up with **Diggers Acetone.**
6. Leave to cure, preferably overnight. Add more layers as required. Additional layers should be completed within 24 hours of the last layer curing. If layers are applied after 24 hours, light sanding between layers is required.

SAFETY

Wear suitable protective clothing, gloves and eye / face protection when using this product.

Code	Pack Size	Unit Barcode	Carton Barcode	Ctn/Plt
FIM00206	6 x 0.25m²	9311052001435	19312852003077	80
FIM00506	6 x 0.50m²	9311052001442	19312852003084	80
FIM0106	6 x 1m²	9311052001459	19312852003091	80

QUEENSLAND
Tel +61 7 3308 5200
Fax +61 7 3308 5201

NEW SOUTH WALES
Tel +61 2 8709 9600
Fax +61 2 9791 5066

VICTORIA
Tel +61 3 9408 4144
Fax +61 3 9408 4155

SOUTH AUSTRALIA
Tel +61 8 8222 1333
Fax +61 8 8260 7883

WESTERN AUSTRALIA
Tel +61 8 9352 3000
Fax +61 8 9352 3033

MATERIAL SAFETY DATA SHEET

SECTION 1 IDENTIFICATION OF THE MATERIAL AND SUPPLIER

Product Name: FIBREGLASS MATTING

Company: Recochem Inc. ABN: 69 010 485 999
Address : 1809 Lytton Road, Lytton, Queensland 4178
Phone: (07) 3308 5200 Fax: (07) 3308 5201
Emergency Telephone Number: (07) 3308 5200 Day, After Hours 1300 131 001

Other Names: None
Manufacturer's Product Code: FIM
Recommended Use: Thermal, acoustic insulation

SECTION 2 HAZARDS IDENTIFICATION

NOT CLASSIFIED AS HAZARDOUS ACCORDING TO CRITERIA OF WORKSAFE AUSTRALIA
NOT A DANGEROUS GOODS ACCORDING TO THE CRITERIA OF THE ADG CODE

Symbols: None
Risk Phrases: None
Safety Phrases: S2 - Keep out of the reach of children

SECTION 3 COMPOSITION / INFORMATION ON INGREDIENTS

Composition

Chemical Entity	*CAS Number*	*Proportion (%)*
Oxides of silicon, aluminium, calcium, boron and magnesium fused in an amorphous state	Not applicable	100

SECTION 4 FIRST AID MEASURES

FIRST AID TREATMENT

Swallowed: Rinse mouth and lips with water, do NOT induce vomiting. Rinse mouth with water ensuring that the mouth wash is not swallowed. Give water to drink to dilute stomach contents. If symptoms persist, seek medical attention.

Eye: If in eyes, hold eyes open, flood with water for at least 15 minutes. If symptoms such as irritation or redness persist, seek medical attention.

Skin: If skin contact occurs, remove contaminated clothing and wash skin thoroughly with water and follow by washing with soap if available. If irritation occurs seek medical advice.

Inhaled: Remove victim from exposure if safe to do so. If rapid recovery does not occur, transport to nearest medical facility for additional treatment. Remove contaminated clothing.

First Aid facilities: Potable water should be available to rinse eyes or skin. Provide eye baths and safety showers.
Advice to Doctor: Treat symptomatically.
Additional Information: None available.

SECTION 5 FIRE FIGHTING MEASURES

Specific Hazards: None.
Hazards from combustion products: None.
Fire Fighting Media and Instructions: None required.
Additional Information: None.

SECTION 6 ACCIDENTAL RELEASE MEASURES

Observe all local and national regulations.

Spills and Disposal: Best cleaned up by vacuum device to avoid generating airborne dust. Keep product out of storm water and sewer drains.

SECTION 7 HANDLING AND STORAGE

Precautions for Safe Handling and Storage: Avoid breathing of or contact with material. Use in well ventilated areas. Wash thoroughly after handling. Avoid contact with skin and eyes and clothing. Do not empty into drains. Do not eat, drink or smoke in contaminated areas. Before eating, drinking or smoking, remove contaminated clothing and wash hands. Protect from moisture to prevent hardening.
Flammability: Non-flammable.

SECTION 8 EXPOSURE CONTROLS / PERSONAL PROTECTION

Exposure Standards: Worksafe Australia has set an exposure standard 0.5 fibre/ml for ceramic fibres.
Biological Limit Values: No biological limit allocated.

Personal Protective Equipment:
Respiratory Protection: If inhalation risk exists a half face respirator with particulate filter should be worn.
Hand Protection: Use impervious gloves and footwear such as PVC.
Eye Protection: Wear splash resistant safety glasses or a face shield.
Protective Clothing: Use chemical resistant glove/gauntlets, boots and apron.
Engineering Controls: Ensure that adequate ventilation is provided. Maintain air concentrations below recommended exposure standards. Avoid generating and inhaling dust. Keep containers closed when not in use.

SECTION 9 PHYSICAL AND CHEMICAL PROPERTIES

PHYSICAL DESCRIPTION / CHEMICAL PROPERTIES

Appearance	Yellow-white fibres bound together in strands
Odour	No distinctive odour
pH:	N/A
Vapour Pressure (mmHg @ 20°C):	Not applicable
Vapour Density (air = 1)	N/A
Boiling Point (°C):	No Data
Freezing/Melting Point (°C):	800
Solubility in Water	None
Specific Gravity (g/ml @ 15°C):	2.5 – 2.8
Flashpoint (°C):	Not relevant
Flammability Limits (%):	Not relevant
Auto Ignition Temperature (°C):	Not available
Percent Volatiles	0

SECTION 10 STABILITY AND REACTIVITY

Chemical Stability: Stable under normal conditions of use.
Conditions to Avoid: Normal storage conditions are adequate.
Incompatible Materials: Not available.
Hazardous Decomposition Products: None.

SECTION 11 TOXICOLOGICAL INFORMATION

HEALTH EFFECTS

Acute:

Swallowed: Unlikely under normal use. May cause gastro-intestinal disturbance, nausea, vomiting and diarrhoea. If swallowed seek medical advice.
Eye: Irritating to eyes. Abrasive action may cause damage to the outer surface of the eye.
Skin: Slightly to moderately irritating. May cause irritation and inflammation due to mechanical abrasive action of sharp broken fibre ends.

Inhaled: May cause respiratory tract irritation. Pre-existing respiratory problems may be aggravated by excessive particle inhalation.

Chronic: Prolonged or repeated inhalation of respirable size particles may cause inflammation of the lung leading to chest pain, difficult breathing, coughing and possible fibrotic change in the lungs.

SECTION 12 ECOLOGICAL INFORMATION

Ecotoxicity: No data.
Mobility: A low mobility would be expected in a landfill scenario
Persistance/degradability: Product is persistent with very low degradability.

SECTION 13 DISPOSAL CONSIDERATIONS

Disposal Methods: Ensure waste disposal conforms to local waste disposal regulations.

SECTION 14 TRANSPORT INFORMATION

UN Number:	N/A	Proper Shipping Name:	N/A
Class:	N/A	Subsidiary Risk:	N/A
Packing Group:	N/A	Hazchem Code:	N/A
Special Precautions for User:	None		

SECTION 15 REGULATORY INFORMATION

Poisons Schedule : None allocated
AICS : Listed
Dangerous Goods Initial Emergency Response Guide (SAA/SNZ HB76:2010) : N/A

SECTION 16 OTHER INFORMATION

Further Information may be obtained by contacting Recochem on (07) 3308 5200

Safety data sheet

according to 1907/2006/EC, Article 31 (REACH)

Printing date 12.07.2013 *Revision: 12.07.2013*

1 Identification of the substance/mixture and of the company/undertaking

· ***Product identifier***

· ***Trade name:*** Sodium hydroxide, pellets, reagent grade, ACS, ISO, Reag. Ph Eur

· ***Article number:*** SO0425
· ***CAS Number:***
1310-73-2
· ***EC number:***
215-185-5
· ***Index number:***
011-002-00-6
· ***Registration number*** 01-2119457892-27-XXXX
· ***Relevant identified uses of the substance or mixture and uses advised against***
No further relevant information available.
· ***Application of the substance / the preparation:*** Laboratory reagent

· ***Details of the supplier of the safety data sheet***
· ***Manufacturer/Supplier:***
Scharlab, S.L.
C/Gato Pérez, 33. Pol.Ind. Mas d'en Cisa
08181 Sentmenat (Barcelona) SPAIN
Tel: (+34) 93 715 19 39 - FAX: (+34) 93 715 27 65
email: scharlab@scharlab.com
Internet Web Site: www.scharlab.com
· ***Regional representation:***
Chem-Supply Pty Ltd
38-50 Bedford Street
Gillman South Australia 5013 AUSTRALIA
Tel: (08) 8440 2000 - FAX: (08) 8440 2001
email: info@chemsupply.com.au
Internet Web Site: www.chemsupply.com.au

· ***Further information obtainable from:*** technical department
· ***Emergency telephone number:***
EMERGENCY CONTACT NUMBER: +61 08 8440 2000
Business hours: 8:30am to 5:00pm, Monday to Friday.

2 Hazards identification

· ***Classification of the substance or mixture***

GHS05 corrosion

H314 Causes severe skin burns and eye damage.

· ***Classification according to Directive 67/548/EEC or Directive 1999/45/EC***

C; Corrosive

R35: Causes severe burns.
· ***Information concerning particular hazards for human and environment:*** Not applicable.

· ***Label elements***
· ***GHS label elements***
The substance is classified and labelled according to the Globally Harmonized System (GHS).

(Contd. on page 2)

Safety data sheet
according to 1907/2006/EC, Article 31 (REACH)

Printing date 12.07.2013 *Revision: 12.07.2013*

Trade name: Sodium hydroxide, pellets, reagent grade, ACS, ISO, Reag. Ph Eur

(Contd. of page 1)

· ***Hazard pictograms***

GHS05

· ***Signal word*** Danger
· ***Hazard statements***
Causes severe skin burns and eye damage.
· ***Precautionary statements***
Do not breathe dust/fume/gas/mist/vapours/spray.
IF ON SKIN (or hair): Remove/Take off immediately all contaminated clothing. Rinse skin with water/shower.
IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.
Immediately call a POISON CENTER or doctor/physician.
Store locked up.
Dispose of contents/container in accordance with local/regional/national/international regulations.
· ***Information concerning particular hazards for human and environment:***
· ***Safety phrases:***
1/2 Keep locked up and out of the reach of children.
26 In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.
37/39 Wear suitable gloves and eye/face protection.
45 In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible).
· ***Other hazards***
· ***Results of PBT and vPvB assessment***
· ***PBT:*** Not applicable.
· ***vPvB:*** Not applicable.

3 Composition/information on ingredients

· ***Chemical characterization: Substances***
· ***CAS No. Description***
1310-73-2 sodium hydroxide
· ***Identification number(s)***
· ***EC number:*** 215-185-5
· ***Index number:*** 011-002-00-6

4 First aid measures

· ***Description of first aid measures***
· ***General information:*** Immediately remove any clothing soiled by the product.
· ***After inhalation:***
In case of unconsciousness place patient stably in side position for transportation.
· ***After skin contact:*** Immediately wash with water and soap and rinse thoroughly.
· ***After eye contact:***
Rinse opened eye for several minutes under running water. Then consult a doctor.
· ***After swallowing:*** Drink plenty of water and provide fresh air. Call for a doctor immediately.
· ***Information for doctor:***
· ***Most important symptoms and effects, both acute and delayed***
No further relevant information available.

(Contd. on page 3)

Safety data sheet
according to 1907/2006/EC, Article 31 (REACH)

Printing date 12.07.2013 *Revision: 12.07.2013*

Trade name: Sodium hydroxide, pellets, reagent grade, ACS, ISO, Reag. Ph Eur

(Contd. of page 2)

· ***Indication of any immediate medical attention and special treatment needed***
No further relevant information available.

5 Firefighting measures

· ***Extinguishing media***
· ***Suitable extinguishing agents:***
CO2, powder or water spray. Fight larger fires with water spray or alcohol resistant foam.
· ***Special hazards arising from the substance or mixture***
No further relevant information available.
· ***Advice for firefighters***
· ***Protective equipment:*** No special measures required.
· ***Hazchem code:*** 2W

6 Accidental release measures

· ***Personal precautions, protective equipment and emergency procedures***
Wear protective equipment. Keep unprotected persons away.
· ***Environmental precautions:*** Do not allow to enter sewers/ surface or ground water.
· ***Methods and material for containment and cleaning up:***
Use neutralizing agent.
Dispose contaminated material as waste according to item 13.
Ensure adequate ventilation.
· ***Reference to other sections***
See Section 7 for information on safe handling.
See Section 8 for information on personal protection equipment.
See Section 13 for disposal information.

7 Handling and storage

· ***Handling:***
· ***Precautions for safe handling*** Thorough dedusting.
· ***Information about fire - and explosion protection:*** No special measures required.

· ***Conditions for safe storage, including any incompatibilities***
· ***Storage:***
· ***Requirements to be met by storerooms and receptacles:*** No special requirements.
· ***Information about storage in one common storage facility:*** Not required.
· ***Further information about storage conditions:*** Keep container tightly sealed.
· ***Specific end use(s)*** No further relevant information available.

8 Exposure controls/personal protection

· ***Additional information about design of technical facilities:*** No further data; see item 7.

· ***Control parameters***
· ***Ingredients with limit values that require monitoring at the workplace:***

1310-73-2 sodium hydroxide

NES 2* mg/m³
*Peak limitation

· ***Additional information:*** The lists valid during the making were used as basis.

(Contd. on page 4)

Safety data sheet
according to 1907/2006/EC, Article 31 (REACH)

Printing date 12.07.2013 *Revision: 12.07.2013*

Trade name: Sodium hydroxide, pellets, reagent grade, ACS, ISO, Reag. Ph Eur

(Contd. of page 3)

· ***Exposure controls***
· ***Personal protective equipment:***
· ***General protective and hygienic measures:***
Keep away from foodstuffs, beverages and feed.
Immediately remove all soiled and contaminated clothing
Wash hands before breaks and at the end of work.
Avoid contact with the eyes and skin.
· ***Respiratory protection:*** Not required.
· ***Protection of hands:***

Protective gloves

The glove material has to be impermeable and resistant to the product/ the substance/ the preparation.
Due to missing tests no recommendation to the glove material can be given for the product/ the preparation/ the chemical mixture.
Selection of the glove material on consideration of the penetration times, rates of diffusion and the degradation
· ***Material of gloves***
The selection of the suitable gloves does not only depend on the material, but also on further marks of quality and varies from manufacturer to manufacturer.
· ***Penetration time of glove material***
The exact break through time has to be found out by the manufacturer of the protective gloves and has to be observed.
· ***Eye protection:***

Tightly sealed goggles

9 Physical and chemical properties

· ***Information on basic physical and chemical properties***
· ***General Information***
· ***Appearance:***

Form:	Solid
Colour:	White
· ***Odour:***	Odourless
· ***Odour threshold:***	Not determined.
· ***pH-value:***	Not applicable.
· ***Change in condition***	
Melting point/Melting range:	319 °C
Boiling point/Boiling range:	1390 °C
· ***Flash point:***	Not applicable.
· ***Flammability (solid, gaseous):***	Product is not flammable.
· ***Ignition temperature:***	
Decomposition temperature:	Not determined.
· ***Self-igniting:***	Not determined.

(Contd. on page 5)

Safety data sheet
according to 1907/2006/EC, Article 31 (REACH)

Printing date 12.07.2013 *Revision: 12.07.2013*

Trade name: Sodium hydroxide, pellets, reagent grade, ACS, ISO, Reag. Ph Eur

(Contd. of page 4)

· **Danger of explosion:** Product does not present an explosion hazard.

· **Explosion limits:**
Lower: Not determined.
Upper: Not determined.

· **Vapour pressure at 800 °C:** 3.5 hPa

· **Density at 20 °C:** 2.13 g/cm³
· **Relative density** Not determined.
· **Vapour density** Not applicable.
· **Evaporation rate** Not applicable.

· **Solubility in / Miscibility with water at 20 °C:** 420 g/l

· **Partition coefficient (n-octanol/water):** Not determined.

· **Viscosity:**
Dynamic: Not applicable.
Kinematic: Not applicable.
· **Other information** No further relevant information available.

10 Stability and reactivity

· **Reactivity**
· **Chemical stability**
· **Thermal decomposition / conditions to be avoided:**
No decomposition if used according to specifications.
· **Possibility of hazardous reactions** No dangerous reactions known.
· **Conditions to avoid** No further relevant information available.
· **Incompatible materials:** No further relevant information available.
· **Hazardous decomposition products:** No dangerous decomposition products known.

11 Toxicological information

· **Information on toxicological effects**
· **Acute toxicity:**
· **LD/LC50 values relevant for classification:**
Oral LD50 2000 mg/kg (rat)
· **Primary irritant effect:**
· **on the skin:** Strong caustic effect on skin and mucous membranes.
· **on the eye:** Strong caustic effect.
· **Sensitization:** No sensitizing effects known.
· **Additional toxicological information:**
Swallowing will lead to a strong caustic effect on mouth and throat and to the danger of perforation of esophagus and stomach.

12 Ecological information

· **Toxicity**
· **Aquatic toxicity:** No further relevant information available.
· **Persistence and degradability** No further relevant information available.
· **Behaviour in environmental systems:**
· **Bioaccumulative potential** No further relevant information available.

(Contd. on page 6)

Safety data sheet
according to 1907/2006/EC, Article 31 (REACH)

Printing date 12.07.2013 *Revision: 12.07.2013*

Trade name: Sodium hydroxide, pellets, reagent grade, ACS, ISO, Reag. Ph Eur

(Contd. of page 5)

· ***Mobility in soil*** No further relevant information available.
· ***Additional ecological information:***
· ***General notes:***
Water hazard class 1 (German Regulation) (Assessment by list): slightly hazardous for water
Do not allow undiluted product or large quantities of it to reach ground water, water course or sewage system.
Must not reach sewage water or drainage ditch undiluted or unneutralized.
· ***Results of PBT and vPvB assessment***
· ***PBT:*** Not applicable.
· ***vPvB:*** Not applicable.
· ***Other adverse effects*** No further relevant information available.

13 Disposal considerations

· ***Waste treatment methods***
· ***Recommendation***
Must not be disposed together with household garbage. Do not allow product to reach sewage system.

· ***Uncleaned packaging:***
· ***Recommendation:*** Disposal must be made according to official regulations.
· ***Recommended cleansing agents:*** Water, if necessary together with cleansing agents.

14 Transport information

· ***UN-Number***	
· ***ADG, IMDG, IATA***	UN1823
· ***UN proper shipping name***	
· ***ADG***	1823 SODIUM HYDROXIDE, SOLID
· ***IMDG, IATA***	SODIUM HYDROXIDE, SOLID
· ***Transport hazard class(es)***	

· ***ADG, IMDG, IATA***

· ***Class***	8 Corrosive substances.
· ***Label***	8
· ***Packing group***	
· ***ADG, IMDG, IATA***	II
· ***Environmental hazards:***	
· ***Marine pollutant:***	No
· ***Special precautions for user***	Warning: Corrosive substances.
· ***Danger code (Kemler):***	80
· ***EMS Number:***	F-A,S-B
· ***Segregation groups***	Alkalis
· ***Transport in bulk according to Annex II of MARPOL73/78 and the IBC Code***	Not applicable.

· ***Transport/Additional information:***

· ***ADG***	
· ***Limited quantities (LQ)***	1 kg
· ***Transport category***	2

(Contd. on page 7)

Safety data sheet
according to 1907/2006/EC, Article 31 (REACH)

Printing date 12.07.2013 *Revision: 12.07.2013*

Trade name: Sodium hydroxide, pellets, reagent grade, ACS, ISO, Reag. Ph Eur

(Contd. of page 6)

· ***Tunnel restriction code*** E
· ***UN "Model Regulation":*** UN1823, SODIUM HYDROXIDE, SOLID, 8, II
· ***Hazchem code:*** 2W

15 Regulatory information

· ***Safety, health and environmental regulations/legislation specific for the substance or mixture***
· ***Australian Inventory of Chemical Substances*** Substance is listed.
· ***Standard for the Uniform Scheduling of Drugs and Poisons***

1310-73-2 sodium hydroxide: S5+APPENDI

· ***GHS label elements***
The substance is classified and labelled according to the Globally Harmonized System (GHS).
· ***Hazard pictograms***

GHS05

· ***Signal word*** Danger
· ***Hazard statements***
Causes severe skin burns and eye damage.
· ***Precautionary statements***
Do not breathe dust/fume/gas/mist/vapours/spray.
IF ON SKIN (or hair): Remove/Take off immediately all contaminated clothing. Rinse skin with water/shower.
IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.
Immediately call a POISON CENTER or doctor/physician.
Store locked up.
Dispose of contents/container in accordance with local/regional/national/international regulations.
· ***Chemical safety assessment:*** A Chemical Safety Assessment has not been carried out.

16 Other information

This information is based on our present knowledge. However, this shall not constitute a guarantee for any specific product features and shall not establish a legally valid contractual relationship.

· ***Department issuing MSDS:*** product safety department
· ***Contact:*** msds@scharlab.com
· ***Abbreviations and acronyms:***
RID: Règlement international concernant le transport des marchandises dangereuses par chemin de fer (Regulations Concerning the International Transport of Dangerous Goods by Rail)
ICAO: International Civil Aviation Organization
ADG: Australian Code for the Transport of Dangerous Goods by Road & Rail.
ADR: Accord européen sur le transport des marchandises dangereuses par Route (European Agreement concerning the International Carriage of Dangerous Goods by Road)
IMDG: International Maritime Code for Dangerous Goods
IATA: International Air Transport Association
EINECS: European Inventory of Existing Commercial Chemical Substances
CAS: Chemical Abstracts Service (division of the American Chemical Society)
LC50: Lethal concentration, 50 percent
LD50: Lethal dose, 50 percent

Product code:SO0425
Sodium hydroxide, pellets, reagent grade, ACS, ISO

NaOH
M = 40,00 g/mol
CAS [1310-73-2]
EC number: 215-185-5
Taric code: 2815 11 00 00

Scharlau

Technical Data Sheet

Synonyms
Caustic soda

Specifications

assay (acidimetric)	min. 99,0 %	arsenic (As)	max. 0,0001 %
identity	passes test	calcium (Ca)	max. 0,0005 %
appearance of solution	passes test	copper (Cu)	max. 0,0005 %
carbonates (as Na2CO3)	max. 1,0 %	heavy metals (as Pb)	max. 0,0005 %
chlorides (Cl)	max. 0,0005 %	iron (Fe)	max. 0,0005 %
phosphates (PO4)	max. 0,0005 %	lead (Pb)	max. 0,0002 %
silicates (SiO2)	max. 0,001 %	magnesium (Mg)	max. 0,002 %
sulfates (SO4)	max. 0,0005 %	mercury (Hg)	max. 0,00001 %
ammonium hydroxide precipitate	max. 0,02 %	nickel (Ni)	max. 0,0005 %
total N	max. 0,0003 %	potassium (K)	max. 0,02 %
aluminium (Al)	max. 0,0005 %	zinc (Zn)	max. 0,0005 %

Packaging

SO04250500	500 g	
SO04251000	1 kg	
SO0425005P	5 kg	
SO0425025P	25 kg	

Physical data
- Form: solid
- Spec. density: 2,13 g/cm3
- Solub. in water (20 ºC): soluble
- Melting point: 323 ºC
- Boiling point: 1390 ºC
- pH (50 g/l H2O, 20 ºC) ~ 14

Toxicological data
- MAK: 2 mg/m3
- WGK: 1
- Poison class CH (Swiss): 2

Safety
- Hazard symbols: C (Corrosive)
- EC Index no.: 011-002-00-6
- R: 35
- S: 26-36/37/39-45

Transport/storage
- ADR: 8 C6 II• UN 1823
- IMDG: 8 II• UN 1823
- IATA/ICAO: 8 II• UN 1823
- PAX: 814
- CAO: 816
- LGK: 8 B
- Disposal: 13

Applications
solutions: to neutralize acids, to make sodium salts, to precipitate metals (as hydroxides) from water solutions of their salts.

HUNTSMAN
Composites

MATERIAL SAFETY DATA SHEET

NU-CEARA WAX

Hazardous according to the criteria of NOHSC

COMPANY DETAILS

Company Name: Huntsman Composites
A division of Huntsman Chemical Company Australia Pty. Limited ABN 48 004 146 338
Address: Somerville Road, Brooklyn, VIC 3012
Telephone Number: (03) 9316 3333
Fax Number: (03) 9314 2170
Emergency Telephone Number: **1800 033051 (STD Free - all hours)**

IDENTIFICATION

Product Name: NU-CEARA WAX

Manufacturer's Product Codes: 660185

ADG Code Classification: Does not meet criteria for classification as Dangerous Goods.
Poisons Schedule Number: None allocated
Australian Inventory of Chemical Substances: All components are listed.

Use: Mould release agent.

PHYSICAL DESCRIPTION/PROPERTIES

Appearance: Light brown soft paste.
Boiling Point: Not applicable
Vapour Pressure: Not established
Specific Gravity: Approx. 0.8 @ 25 deg.C (Water=1)
Flash Point: Not available
Flammability Limits: Not available
Solubility in Water: Insoluble

INGREDIENTS

Chemical Name	CAS No.	Proportion, % wt.
Triethanolamine	102-71-6	<5%
Distillates, petroleum, hydrotreated-middle	64742-46-7	10-<30
Kerosene	8008-20-6	30-60
Other ingredients determined not to be hazardous		to 100%

MATERIAL SAFETY DATA SHEET

NU-CEARA WAX

HEALTH HAZARD INFORMATION

HEALTH EFFECTS

Acute - Swallowed:
Causes irritation of the mouth, throat and stomach and effects on the central nervous system. Symptoms may include nausea, vomiting and diarrhea, headaches, dizziness and drowsiness, incoordination and possibly loss of consciousness.

Acute - Eye:
May cause mild eye irritation.

Acute - Skin:
Irritating to skin. Prolonged or repeated skin contact may result in irritant and/or allergic contact dermatitis.

Acute - Inhaled:
May cause irritation to the respiratory system. Inhalation of high concentrations of vapour can have effects on the central nervous system (CNS) resulting in headaches, dizziness, unco-ordination, nausea, loss of appetite and possibly loss of consciousness.

Chronic:
Prolonged or repeated skin contact may result in irritant and/or allergic contact dermatitis.

FIRST AID

Swallowed:
If swallowed, do NOT induce vomiting. Give a glass of water. Never give drink to an unconscious person. Transport to a doctor or hospital quickly. For further advice call Poisons Information Centre (Phone Australia 13 1126).

Eye:
Immediately flush with plenty of water for at least 15 minutes, with eyelids held open. Seek immediate medical advice.

Skin:
Wash skin thoroughly with soap and water. Remove contaminated clothing Wash clothing before re-use.
If irritation persists, seek medical advice.

Inhaled:
Remove to fresh air. Seek medical assistance if discomfort persists.

First Aid Facilities:
Provide eye baths and safety showers close to areas where there is potential for eye and skin contact.

ADVICE TO DOCTOR

Treat symptomatically.

PRECAUTIONS FOR USE

EXPOSURE STANDARDS

The National Occupational Health and Safety Commission (NOHSC) has not established an exposure standard for this product. NOHSC have established exposure standards for the following components:

Triethanolamine:	TWA 8-hour: 5 ppm, Sensitiser
Oil mist:	TWA 8-hour: 5 mg/m3

Keep exposures as low as practicable within exposure standards.

ENGINEERING CONTROLS

Use only in well ventilated areas. Provide sufficient ventilation to minimise exposure levels within the exposure standards and/or to prevent worker discomfort.

PERSONAL PROTECTION

Avoid breathing vapours. If inhalation risk exists, wear respiratory protection equipment meeting AS/NZS1716 in accordance with AS/NZS1715. For low vapour concentrations, an air-purifying respirator fitted with organic vapour filter may be suitable. Air-purifying respirators do not provide protection in oxygen-deficient environments. Avoid contact with skin, eyes and clothing. Wear safety glasses with side-shields, impervious gloves (eg. rubber or PVC), overalls and safety boots. Protective equipment/clothing should meet, and be selected and used in accordance with, the relevant Australian Standards. Consult protective equipment/clothing supplier for appropriate equipment/clothing for a given application. Wash thoroughly after handling. When using, do not eat, smoke or drink. Protective equipment/clothing should be decontaminated before storage or reuse.

FLAMMABILITY

Combustible paste. Keep away from sources of ignition and strong heat.

SAFE HANDLING INFORMATION

STORAGE AND TRANSPORT

Not classified as a Dangerous Goods for transport and storage and handling (See "Identification" section). The product is combustible.

Store under cover, in a well ventilated area. Keep away from sources of ignition sources and strong heat. Keep containers tightly closed. Keep away from strong oxidising agents. Keep away from food, drink and animal feedstuffs.

SPILLS AND DISPOSAL

Spill or Leak Procedures:
Keep unprotected people away. Wear appropriate protective equipment to prevent skin and eye contact and inhalation of vapours (See "Personal Protection" section). Shovel up spillage and seal in properly labelled containers for disposal. Keep out of sewer, stormwater drains and waterways.

Waste Disposal:
The product is a potential environmental pollutant. If feasible, recycle. Otherwise, dispose of by burning in an approved incinerator. In all cases, disposal should be in accordance with regulations.

Containers:
Emptied containers retain product residue. Observe safeguards on label and in this MSDS until container is cleaned, reconditioned or destroyed. In all cases, disposal should be in accordance with regulations.

FIRE/EXPLOSION HAZARD

Combustible paste.

Extinguishing Media:
Foam, carbon dioxide and dry chemical extinguishers may be used. Use water spray to cool exposed closed containers.

Special Fire-Fighting Procedures:
Fire-fighters and others exposed to the products of combustion (see "Hazardous Decomposition Products") should wear self-contained breathing apparatus. Equipment should be thoroughly decontaminated after use.

Hazardous Decomposition Products:
Products of combustion include carbon monoxide, carbon dioxide and nitrogen oxides.

ADDITIONAL INFORMATION

HAZARDOUS SUBSTANCE CLASSIFICATION

Health hazard classification and labelling according to the criteria of NOHSC:

Overall health hazard classification: Xi (IRRITANT)

R38 Irritating to skin.
R43 May cause sensitisation by skin contact.
S24 Avoid contact with skin.
S37 Wear suitable gloves.

HUNTSMAN
Composites

MATERIAL SAFETY DATA SHEET

NU-CEARA WAX

REASONS FOR REVISION

Original

CONTACT POINT

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